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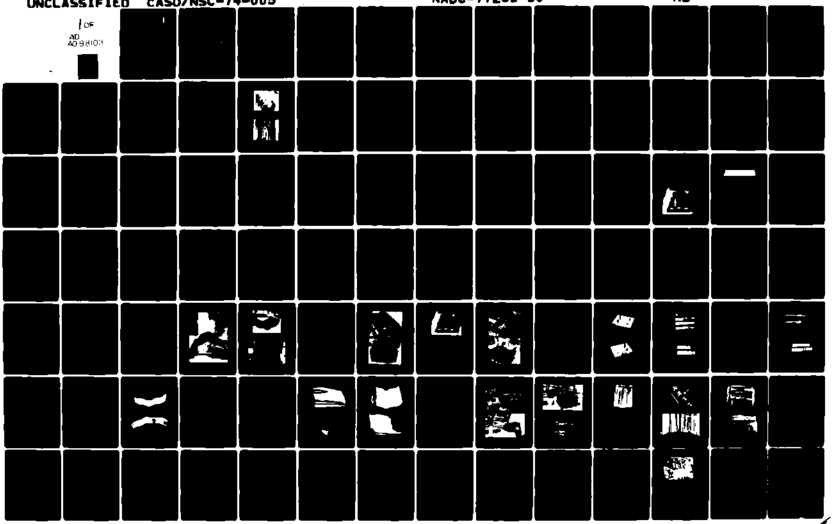

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DEVELOPMENT OF A LOW COST GRAPHITE REINFORCED COMPOSITE SECONDARY STRUCTURAL COMPONENT

FINAL REPORT

JUNE 1974—MARCH 1977

GENERAL DYNAMICS
Convair Division

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The object of this program was to demonstrate the use of graphite-reinforced thermoplastic material to produce low-cost secondary aircraft structure.

The materials evaluation work reported here was conducted under a Convair IRAD program that ran concurrently during the first six months of this program.

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The Model 200 Navy V/STOL Fighter Attack was the aircraft from which was selected a secondary structural component for this study. The main landing gear door was picked, as it met the requirements of being secondary structure, was of convenient size, and was of sufficient complexity to be a challenging application.

During the design study portion of the contract, several door configurations were examined, and a skin-liner concept was chosen for continued work.

The autoclave process was used to consolidate A-S/polysulfone prepreg material. Skins were formed with ceramic tools, and liners were formed with a matched set of metal tools. The bulkheads were formed using aluminum tools with vacuum bagging and autoclave pressure. The door latch and hinges were machined from aluminum by conventional methods.

Adhesive bonding was used to join the skin doubler to the skin, the bulkheads to skin and skin liner, and skin liner to the skin. The door latch and hinges were attached with conventional fasteners. Two rivets were used between each bulkhead and the door skin.

Results of a cost comparison showed that the costs for the composite door were slightly higher (14%) than the similar metal door. All cost elements, except material cost, for the composite door were less than the comparable elements for the metal door. It is therefore concluded that the primary effort reducing thermoplastic composite cost should be directed at the cost of the raw material.

FOREWORD

This report was prepared by Convair Division of General Dynamics Corporation, San Diego, California under the terms of Contract N62269-74-C-0369.

The report covers the entire program from June 1974 through October 1975. The program was sponsored by the Air Vehicle Technology Department (AVTD), Naval Air Development Center (NADC), Warminster, PA, 18974. Mr. Murray Rosenfeld, Code 30334, was the project engineer for NADC.

The following Convair personnel were principal contributors to the program:

D. R. Linsenmann and R. S. Wilson, stress analysis; L. C. May, materials development; R. C. Goad, manufacturing development, tooling, and component manufacturing; and J. S. Comber, cost analysis. Component manufacturing was accomplished in the production plastic shop under the direction of W. R. Walker.

Mr. W. F. Wennhold was program manager for Convair and R. C. Goad was deputy program manager.

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SUMMARY

The object of this program was to demonstrate the use of graphite-reinforced thermoplastic material to produce low-cost secondary structure.

A secondary structural component for this study was selected from the Model 200 Navy V/STOL Fighter-Attack aircraft. The main landing gear door was picked, as it met the requirements of being secondary structure, was of convenient size, and was of sufficient complexity to be a challenging application.

During the design study portion of the contract, several door configurations were examined, and an innovative low cost skin-liner concept was chosen for continued work.

The metal baseline door was assumed to be of a similar configuration. A design for the door was established, and a stress analysis was performed. The door is formed in two parts, a liner and the skin. The liner is a pseudoisotropic laminate 0.08-inch thick. The layup is $[\pm 45/90/\pm 45/90/0_2]_s$ for the liner, and the skin is 0.040-inch thick, ±45° laminate. In areas that are reinforced, ±45° are used. The skin doubler is 0.080-inch and the liner doubler is 0.040-inch. Positive margins of safety are shown on all portions of the door with the minimum margin shown in the torque box stability analysis and the forward beam analysis in areas of high curvature.

Skins were formed with ceramic tools, and liners were formed with a matched set of metal tools. The bulkheads were formed using aluminum tools with vacuum bagging and autoclave pressure. The composite parts were formed using both preconsolidated and unconsolidated sheet forms. The door latch and hinges were machined from aluminum by conventional methods.

Adhesive bonding was used to join the skin doubler to the skin, the bulkheads to skin and skin liner, and skin liner to the skin. The door latch and hinges were attached with conventional fasteners. Two rivets were used between each bulkhead and the door skin.

In keeping with the philosophy established in the design study, the comparison baseline metal door was assumed to be similar in design to the latest composite configuration. The weight of the composite door was calculated to be 13.46 pounds. The corresponding metal door was determined to weigh 18.9 pounds. This is a weight saving for the composite door of approximately 28 percent.

SECTION 1

INTRODUCTION

The objective of this program was to demonstrate the use of graphite-reinforced thermoplastic material to produce a low-cost secondary aircraft structure. A secondary objective was to demonstrate the structural capability of a component fabricated from the reinforced thermoplastic.

1.1 DEMONSTRATION ARTICLE

The component selected for evaluation was the main landing gear (MLG) door of the Convair Model 200 Navy V/STOL fighter-attack aircraft (Figure 1-1). The Model 200 as proposed to the United States Navy incorporated elevons, rudders, speed brakes, wing structure, canard, and lift engine compartment doors of advanced, high-efficiency composites because it was realized that agility and response in takeoff and landing, acceleration, and range or store carrying capability would be further improved by more extensive incorporation of these efficient structures.

The MLG door represents a major secondary structure, yet is small enough in size to be a viable test article in a preliminary R&D program. The configuration represents a very challenging structure to fabricate as it contains a compound curved skin and a hat and bead stiffened liner that require severe forming.

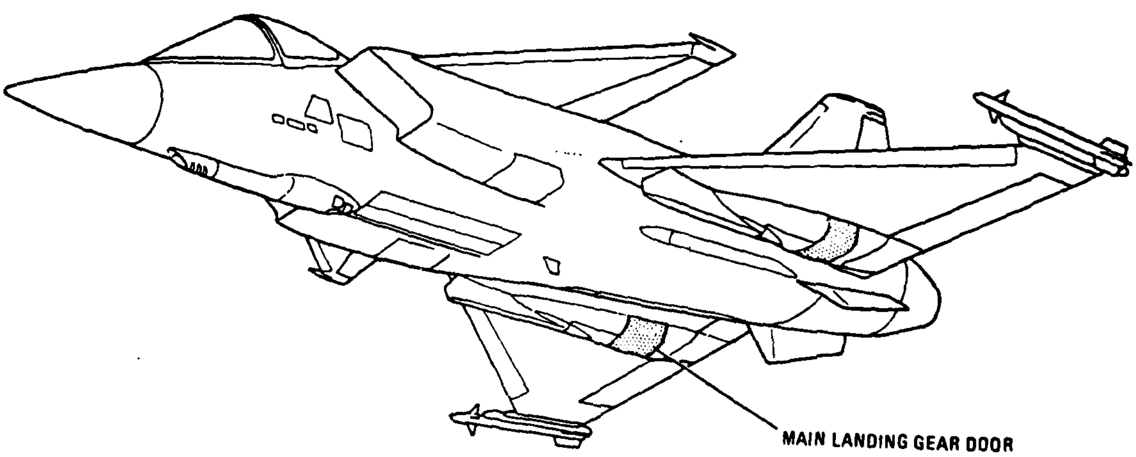


Figure 1-1. Convair Model 200 Navy V/STOL Fighter - Attack Aircraft

The complexity of the component is much greater than that of any part that has been attempted in reinforced thermoplastic. This selection of component was made intentionally with the idea of advancing the state of the art beyond current level.

The completed door was structurally tested at NADC and verified the design calculations and the manufacturing methods.

1.2 PROGRAM PLAN

The overall plan for the program began with a short predesign effort to establish a metal baseline door and to investigate a series of approaches for a composite door. The most promising door configuration was then selected for more detailed analysis and became the demonstration article.

Several components of the door structure were duplicated as subcomponent specimens to verify the manufacturing method and to substantiate the strength analysis.

The door component was then built, straingaged, and shipped to NADC and tested.

A cost analysis was performed to compare costs of the metal and thermoplastic designs, and finally, an evaluation of the costs was performed.

1.3 MATERIAL

The graphite-reinforced thermoplastic material utilized in this program was a continuous, unidirectional tape form of type A-S/P1700, graphite polysulfone obtained from E. I. Dupont de Nemours, Saugus, California. The P1700 resin is a thermoplastic molding compound that is a product of Union Carbide Corp. The composite material has been investigated previously on a Convair IRAD program and by others and has shown properties comparable to type A-S epoxy composites.

SECTION 2

MATERIAL EVALUATION

The material selected for use on this program was Type A-S/P1700 polysulfone. The materials property data for this material were generated on an IRAD program run concurrently with this program. The first property data to be generated were accomplished using material obtained during a 1973 IRAD program.

At the initiation of the program Convair was unable to get any graphite prepreg vendor to commit to supply the necessary material. Due to the petroleum shortage that existed in early 1975 the material suppliers were unable to obtain the raw polysulfone pellets needed to make the prepreg. After much negotiation Dupont was able to obtain the polysulfone pellets from Union Carbide.

An order was placed with Dupont for 45 pounds of material, and after a delay of several months the material was received and the fabrication of material property panels was started.

The initial data showed that the unidirectional compression strength and the transverse tension strength were very low and the $[(0 \pm 60)]$ compression and tension values appeared to be somewhat lower than expected. An investigation was initiated to determine the cause.

Scanning electron microscope photographs were made to determine the failure mechanism. A review of photomicrographs revealed a poor resin-to-fiber bond (Figure 2-1). There were also indications that residual solvent, N-Methyl Pyrrolidone (NMP), was present in the cured laminate. This was observed during post-forming tests when vapors were seen to be driven from the laminate.

It was then suspected that the NMP solvent, because of its high boiling point, was trapped in the laminate along the resin-fiber interface and prevented proper bonding of fibers and resin.

A sample of graphite/polysulfone prepreg was obtained that had been prepared using methylene chloride as a solvent. Methylene chloride has a much lower boiling point than NMP and can be expected to evaporate more fully during the pregreging operations.

A series of tests was conducted. The mechanical properties were excellent, and photomicrographs (Figure 2-2) revealed much improved fiber resin bonding.

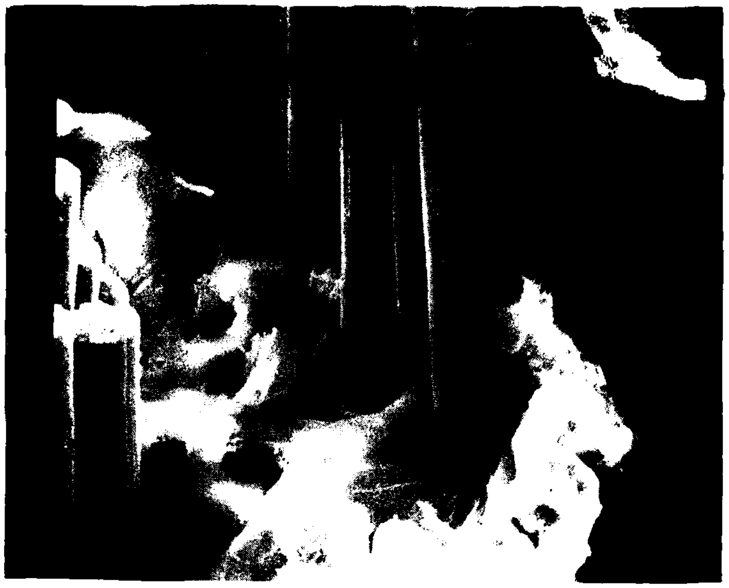


Figure 2-1. Graphite/Polysulfone from NMP Solvent (note clean fibers)

Figure 2-2. Graphite/Polysulfone from Methylene Chloride (resin conforms and adheres to fibers)

A new shipment of graphite/polysulfone (Lot 79-75) prepregged with methylene chloride was received. The prepreg's visual appearance was excellent, with no gaps or splits and good fiber alignment. Properties determined on a panel fabricated from this lot of prepreg are listed in table 2-1.

Table 2-1. Properties of a Panel Fabricated from Lot 79-75

Flexural Strength (ksi)	230.5
Flexural Modulus (psi x 10^6)	17.9
Compression Strength (ksi)	158.2
Short Beam Shear (ksi)	13.1
Resin Content (%)	31.8

New material prepregged with methylene chloride was then ordered to be used for fabrication of the subcomponent specimens and the door component. Several panels were laid up and consolidated from the new material.

SECTION 3

DESIGN STUDIES

The Model 200 aircraft on which this study was based existed only as a paper aircraft at the time this program was undertaken. The design of the metal baseline door was a conceptual design only and the basic lines for the aircraft were established only in the form of small scale drawings.

The first task then was to establish a set of full-scale lines for the door so that the design, analysis, and tooling tasks would have a firm dimensional basis. Lines were drawn for the door portion of the underwing landing gear fairing (Figure 3-1). These lines were then used as the basis for all design study tasks.

3.1 DEFINITION OF METAL BASELINE

Initially the metal baseline used for this study consisted of the metal door defined by the Model 200 predesign study. This configuration, shown in Figure 3-2, was used in the initial door trade studies. After the composite door configuration was established it was decided to use as a baseline a design similar to the composite design as it would provide a more realistic comparison.

3.2 CONCEPTUAL DESIGNS FOR COMPOSITE DOOR

3.2.1 INITIAL STUDY. Initially, five concepts were considered for the composite door. They were:

a. Duplicate of metal door. (as shown in Figure 3-2)

b. Door with partial inner skin and separate ribs.

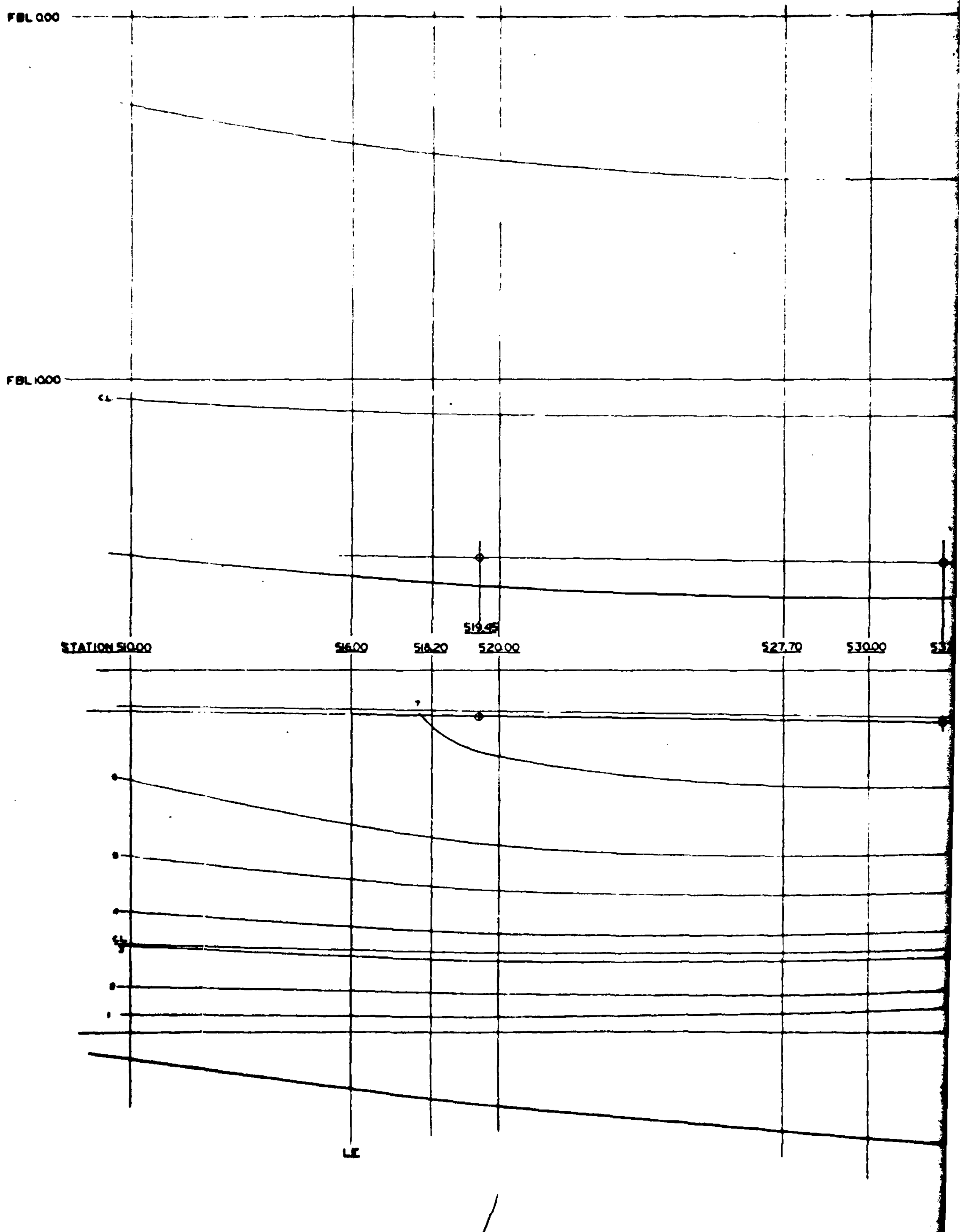
c. Door with full inner skin and separate ribs.

d. Sandwich door.

e. Two-piece door — skin plus stiffened inner panel.

The five concepts for the graphite/thermoplastic door were examined and an analysis was made to determine the best approach for the actual test article. Table 3-1 summarizes the results of the comparison study.

The weight of each of the concepts was estimated and compared with the weight of the baseline metal door (18.9 pounds). As the table shows, a reasonable weight savings was realized in each case. The weight numbers were estimates at this stage of the design.



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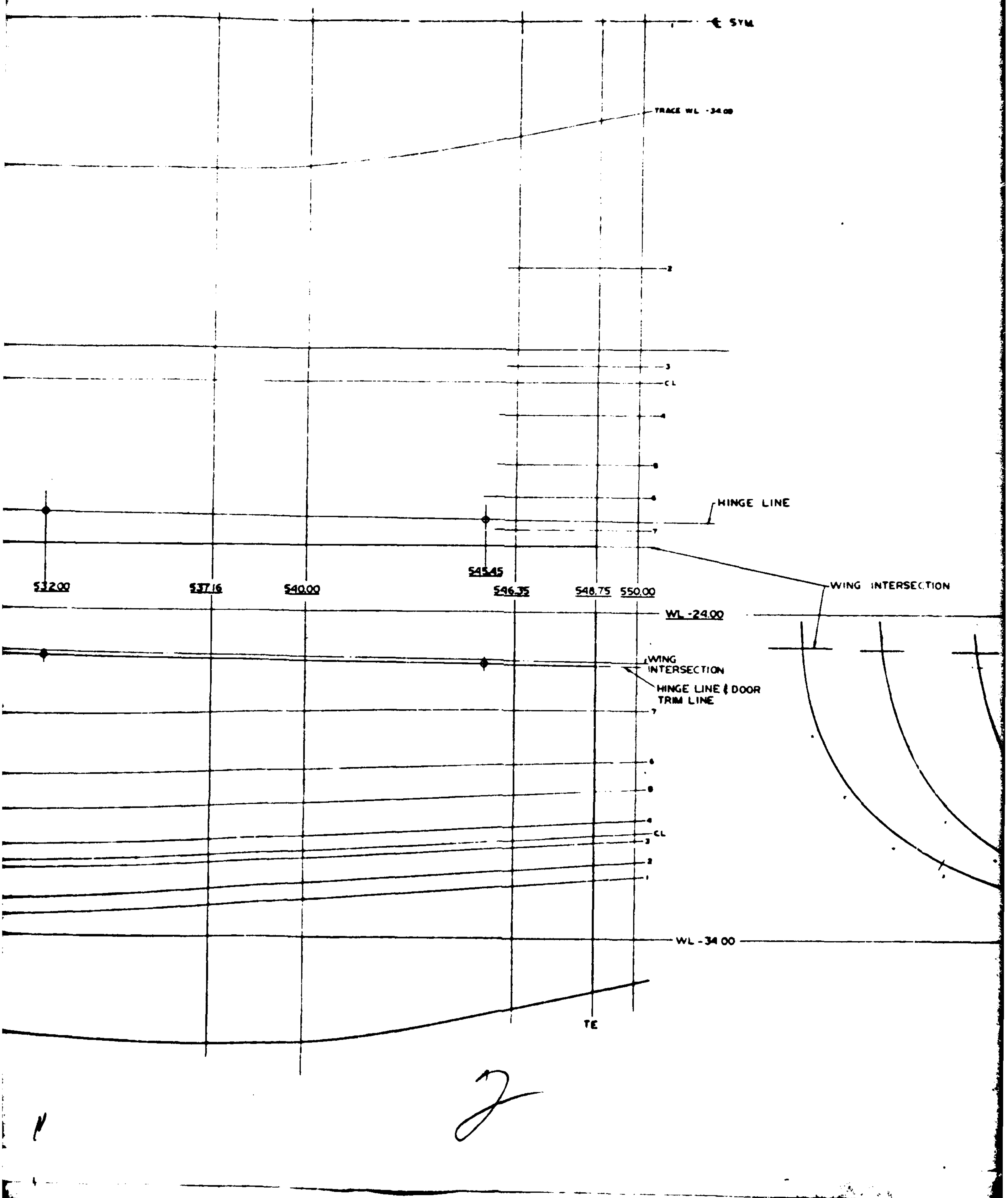

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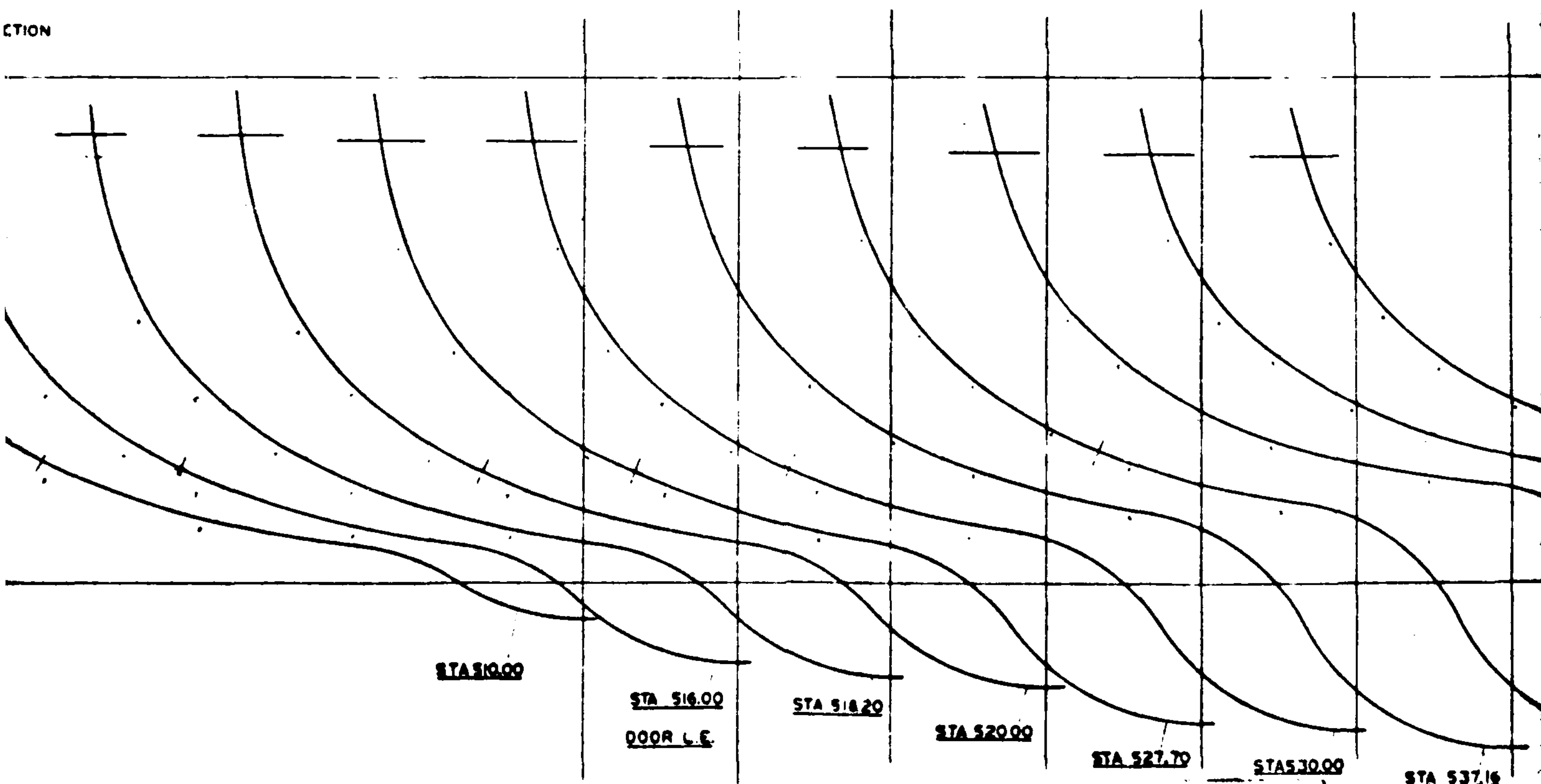

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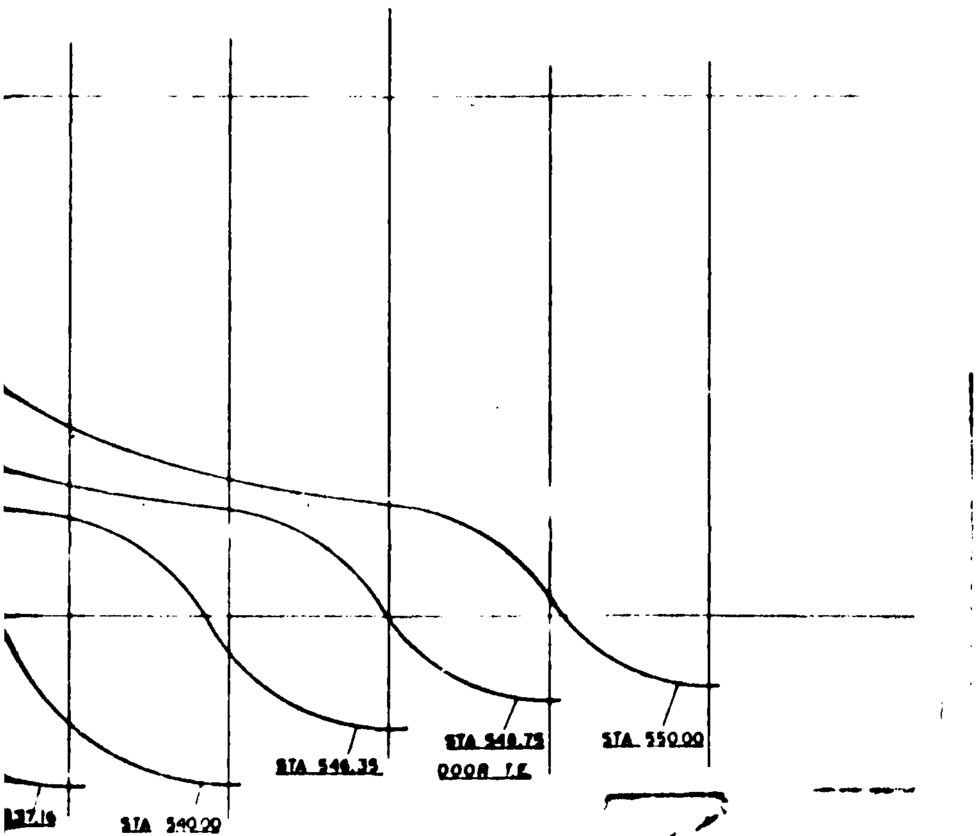


Figure 3-1. Door SkinContour Drawing.

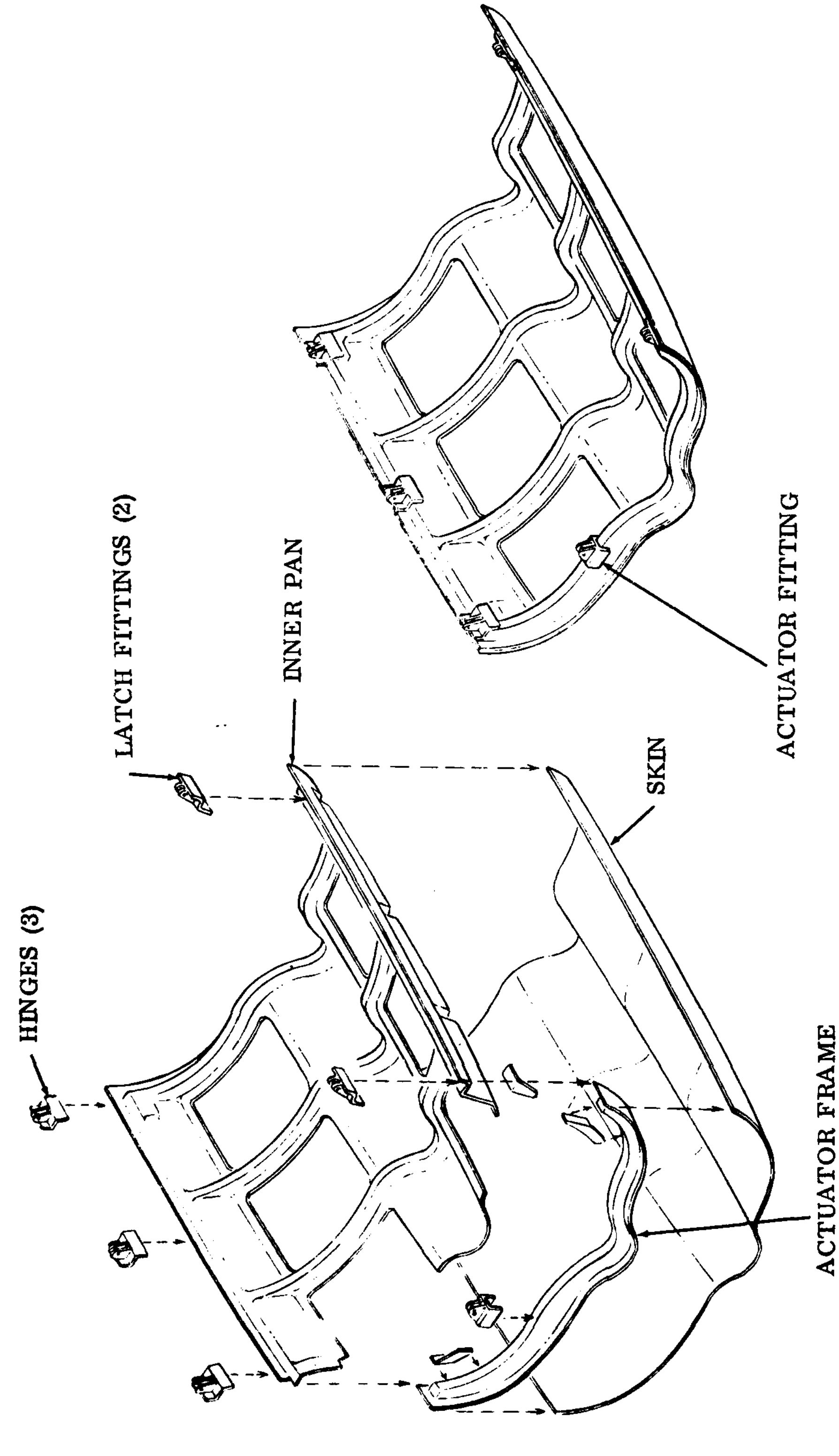


Figure 3-2. Original Baseline Aluminum Door

Table 3-1. Initial Graphite Thermoplastic Door Concept Evaluation

Door Concept	Weight	Saved	No. Unique Parts	Part Complexity*	No. Tools	Tool Complexity*	Assembly Operation	Assembly Complexity*	Number of Bond or Weld Cycles
1 Duplicate Metal	11	31.2	5	4	7	3	Weld and Bond	3	2
2 Partial Inner Skin	10.4	35	25	3	19	4	Weld and Bond	5	5
3 Full Inner Skin	10.7	33	20	2	17	4	Weld and Bond	4	3
4 Sandwich	13.4	16	3	1	8	1	Bond	2	1
5 2 Piece	11.4	28	2	4	5	2	Weld or Bond	1	1

* 1 = Simplest

The manufacturing cost of each was estimated by means of the factors shown in the table. In all cases the two hinge fittings, two latch fittings and the single actuator fitting were not included in the manufacturing analysis. Each is a machined aluminum fitting, and although slightly different in detail design, all are sufficiently similar to be considered common hardware. The door concepts are pictured in Figures 3-3 through 3-7.

3.2.2 CONCEPTUAL DESIGN STUDY. The two most promising concepts were selected for more detailed study. The two-piece door appeared to be the best choice for cost reduction and to demonstrate the use of thermoplastic material. Additional work was also requested on the sandwich door by NADC personnel.

The two-piece door initially shown had what appeared to be forming problems; consequently, a second concept was devised that would avoid most of those problems.

3.2.2.1 Sandwich Configuration. The sandwich configuration consists of an outer skin, an inner skin with integrally formed closures, and a honeycomb core of heat-resistant phenolic/fiberglass. The skins are hot formed to the proper contour and then secondarily bonded to each other and to the core. Hinge, latch, and actuator fittings are conventionally machined aluminum details bolted into inserts in potted zones of the honeycomb core.

The sandwich configuration offers a maximum of bending rigidity for a given material within the design envelope. Torsional rigidity is the result of the single closed cell formed by the facesheets separated by core. A disadvantage to the sandwich design is its inherent maintainability problem.

Since load magnitudes varied significantly in the door, a least-weight design would feature tailored skins. However, in many areas of this design, optimum skin gages would fall below minimum gages. (For this study the minimum gage for manufacturing was set at 0.015 inch.) A least-weight design, constrained to a minimum gage for manufacturing of 0.015 inch is shown in Figure 3-8. The layup of 66% 0° plies and 34% $\pm 60°$ plies was selected with the help of a computer optimization routine, TM1. This layup requires the use of 0.0025-inch/ply prepreg, which must be specially ordered. In addition, a 0.015-inch skin in a MLG door will be prone to damage resulting from ground handling and runway debris. Consequently, a more practical design was developed.

Increasing the skin to a constant 0.030 inch on both facesheets allowed the use of conventional 0.005-inch/ply prepreg and provided an inherently more damage-tolerant structure. The weight penalty of this more practical approach was warranted considering the environment to which the MLG door will be exposed. Figure 3-9 illustrates this configuration.

3.2.2.2 Shell/Liner Configuration. The shell/liner configuration consists of an outer skin, similar to that used in the sandwich configuration, bonded to a complex-formed inner skin. The outer skin or shell provides the aerodynamic contour while

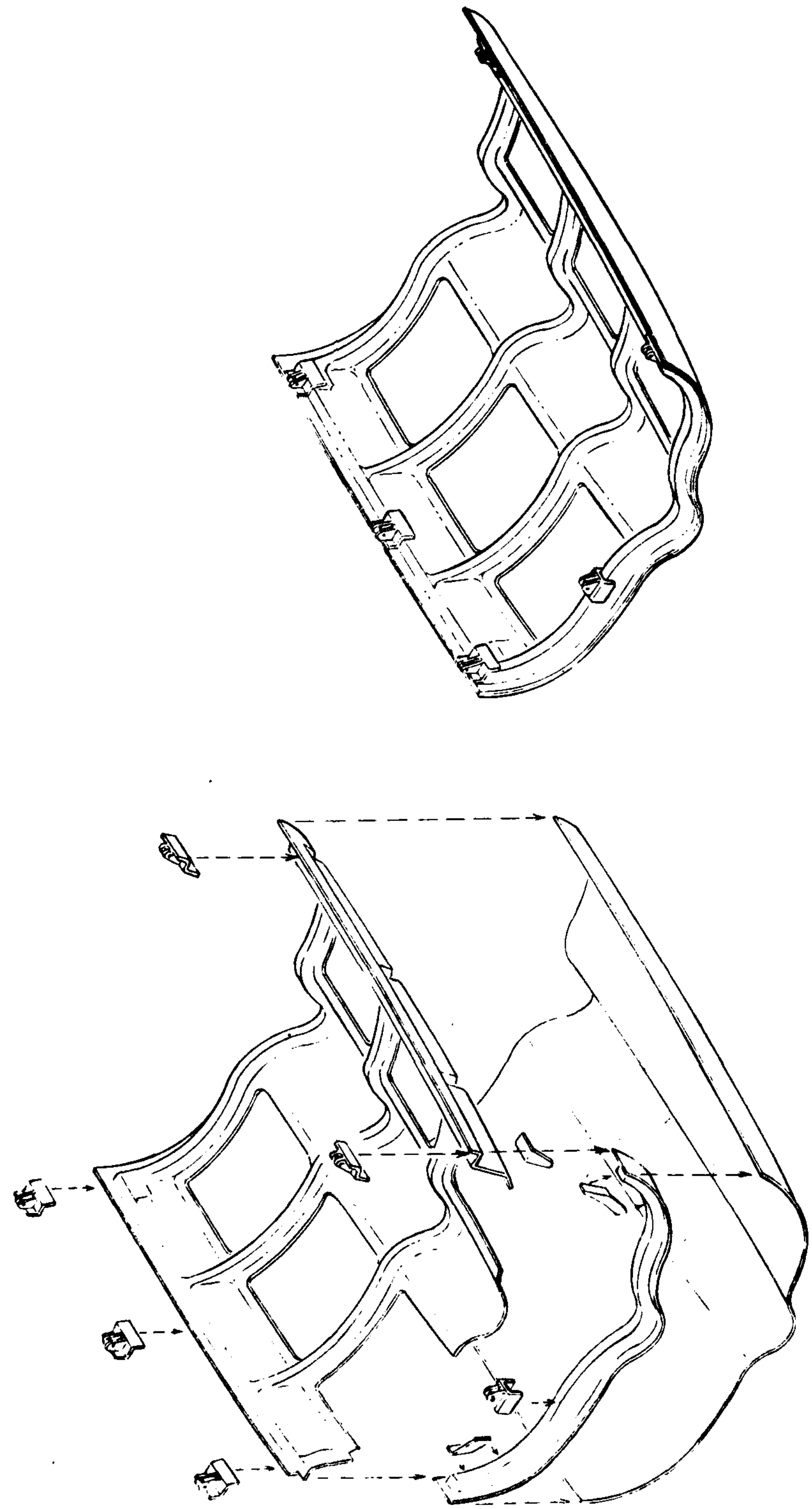


Figure 3-3. Graphite Thermoplastic MLG Door, Concept 1 — Metal Replacement

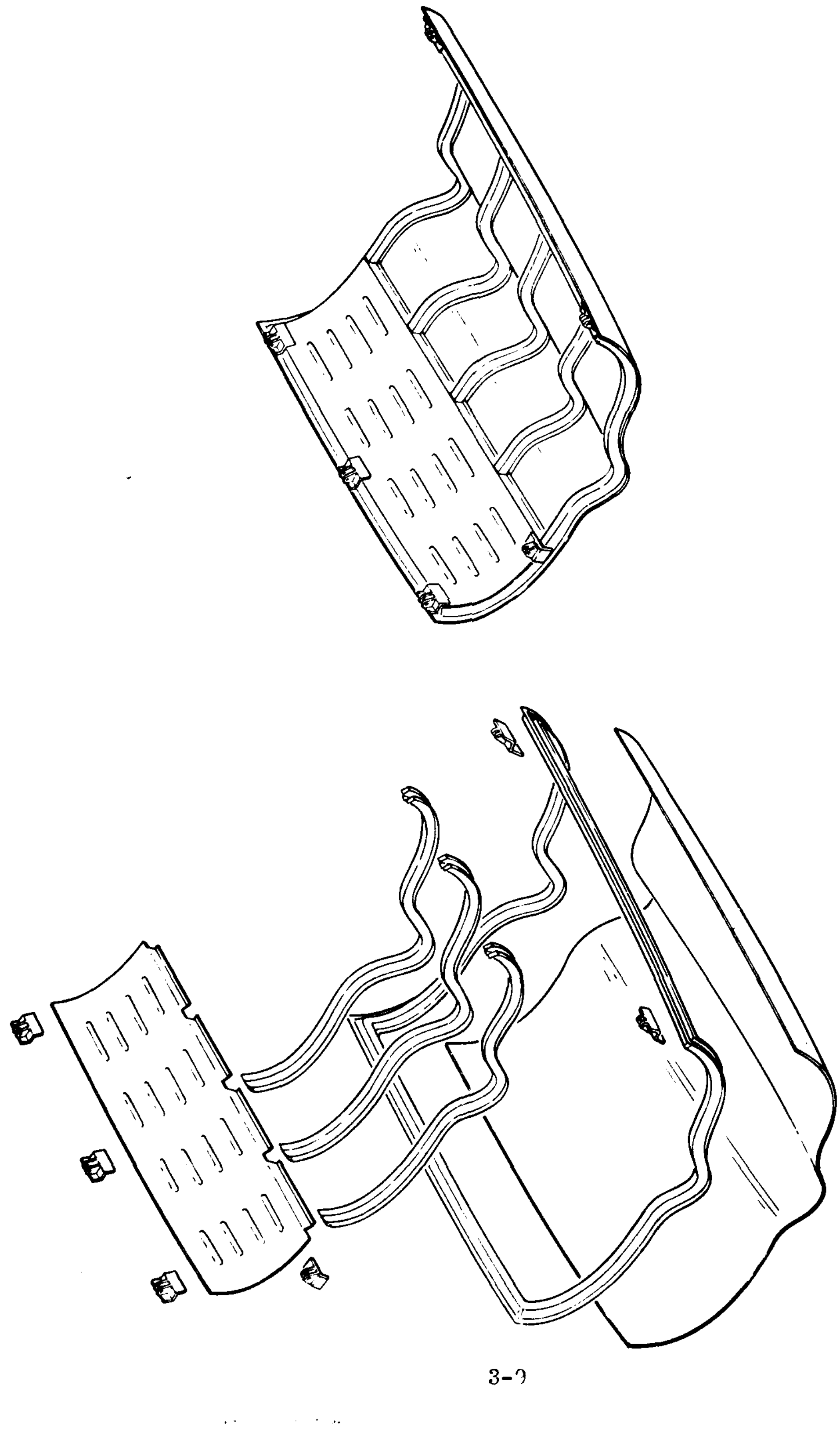


Figure 3-4. Graphite Thermoplastic MLG Door, Concept 2 — Partial Inner Skin

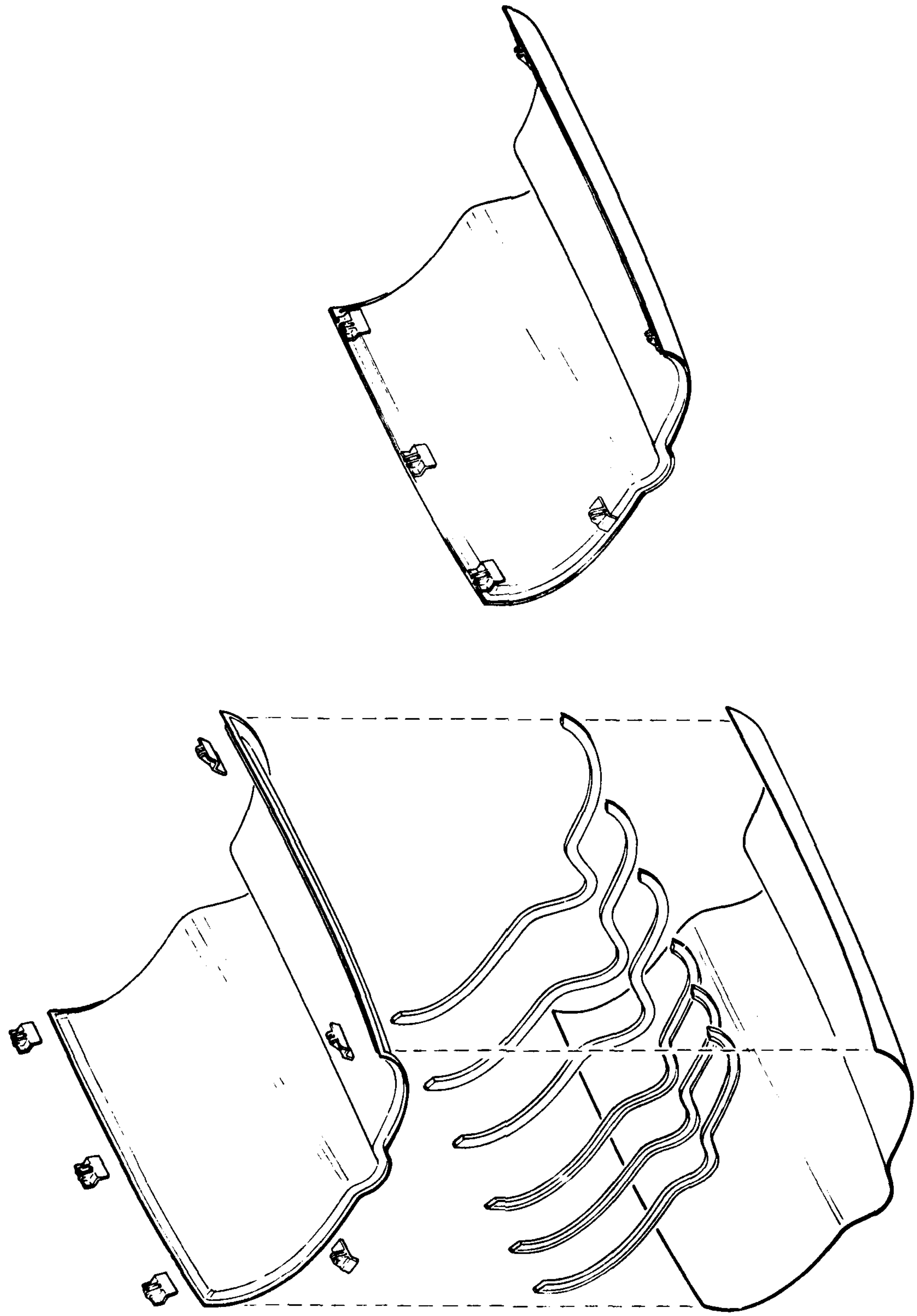


Figure 3-5. Graphite Thermoplastic MLG Door, Concept 3 — Full Inner Pan

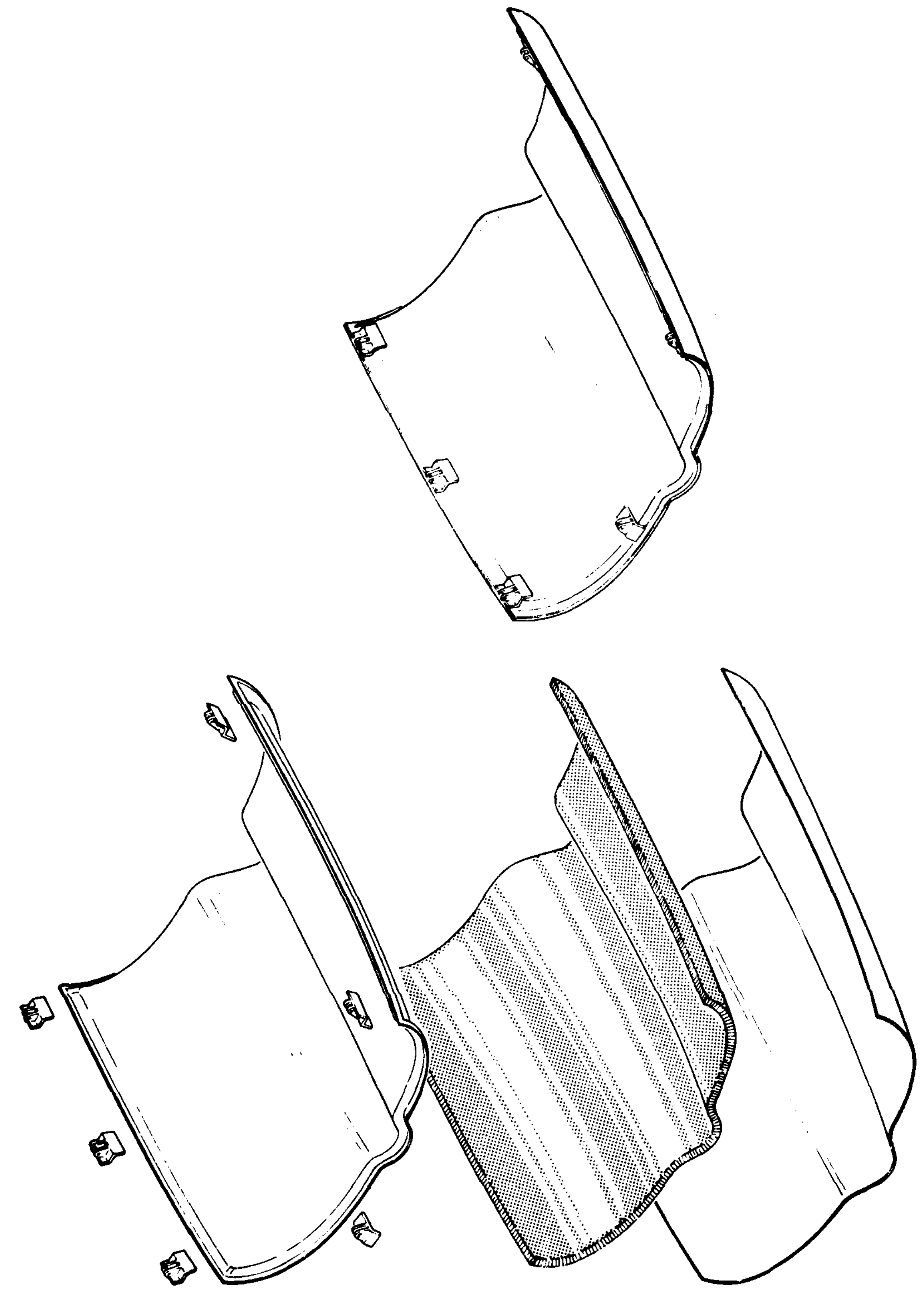


Figure 3-6. Graphite Thermoplastic MLG Door, Concept 4 — Sandwich Construction

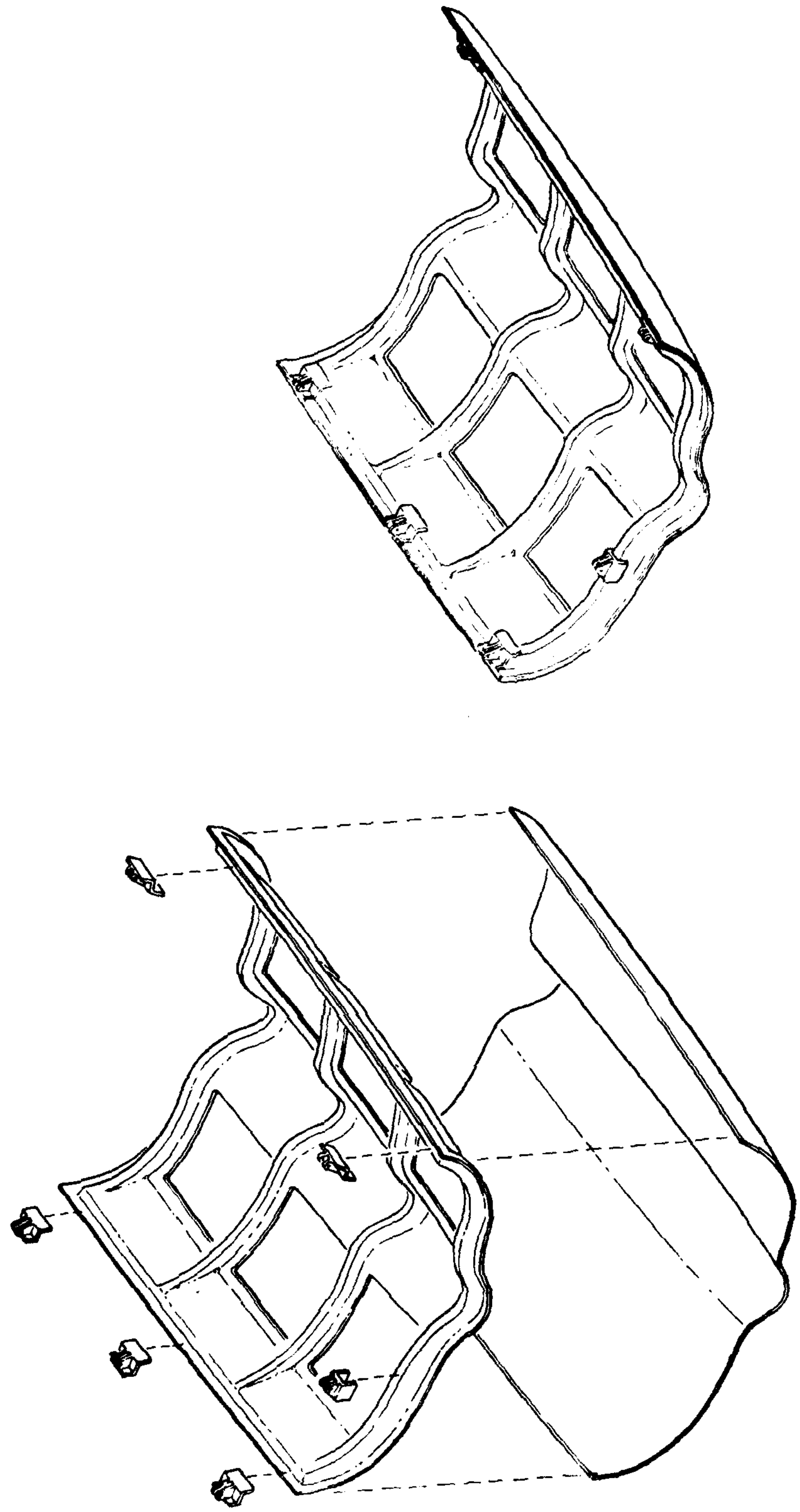


Figure 3-7. Graphite Thermoplastic MLG Door, Concept 5 — Two Piece Construction

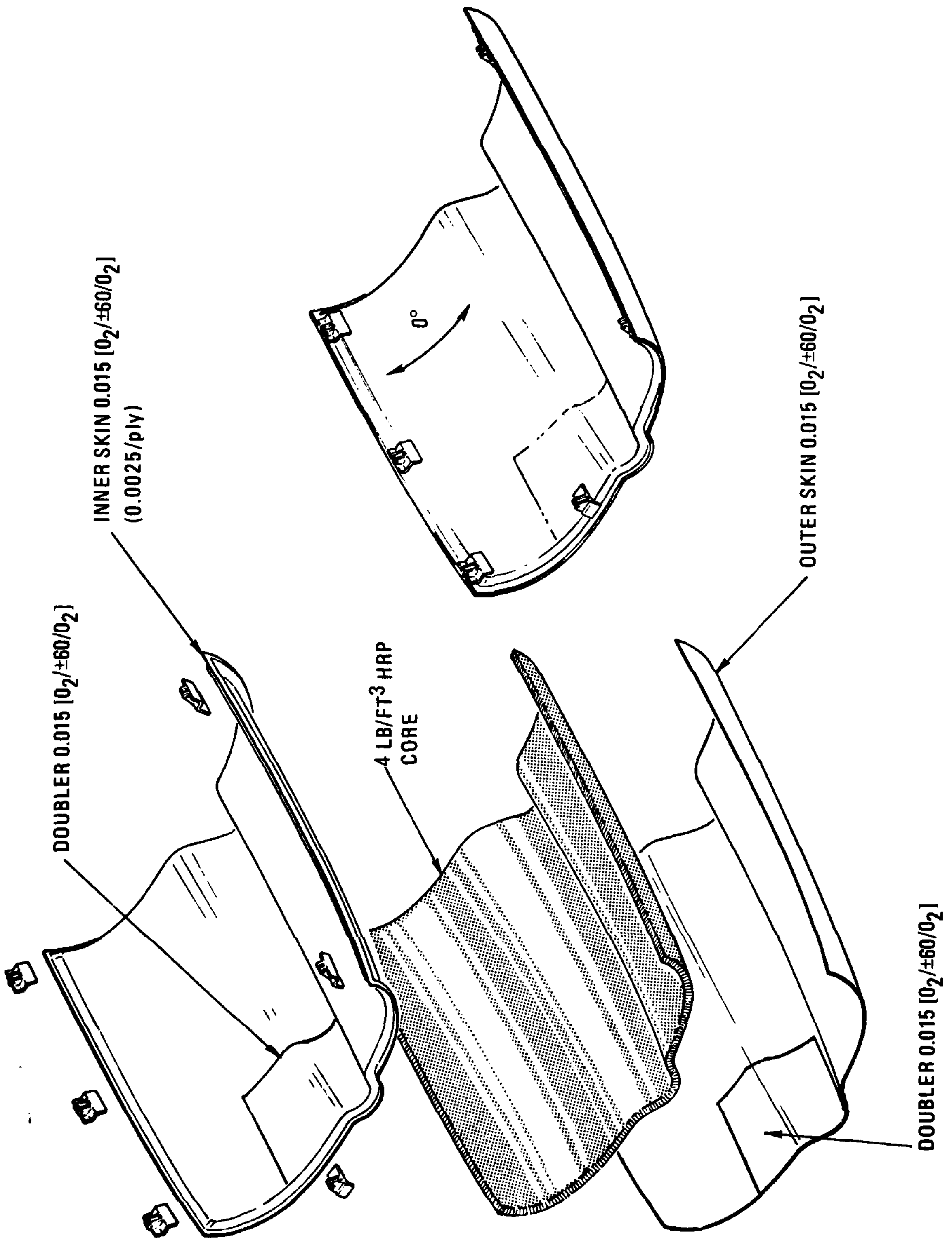


Figure 3-8. Minimum Weight Sandwich Door

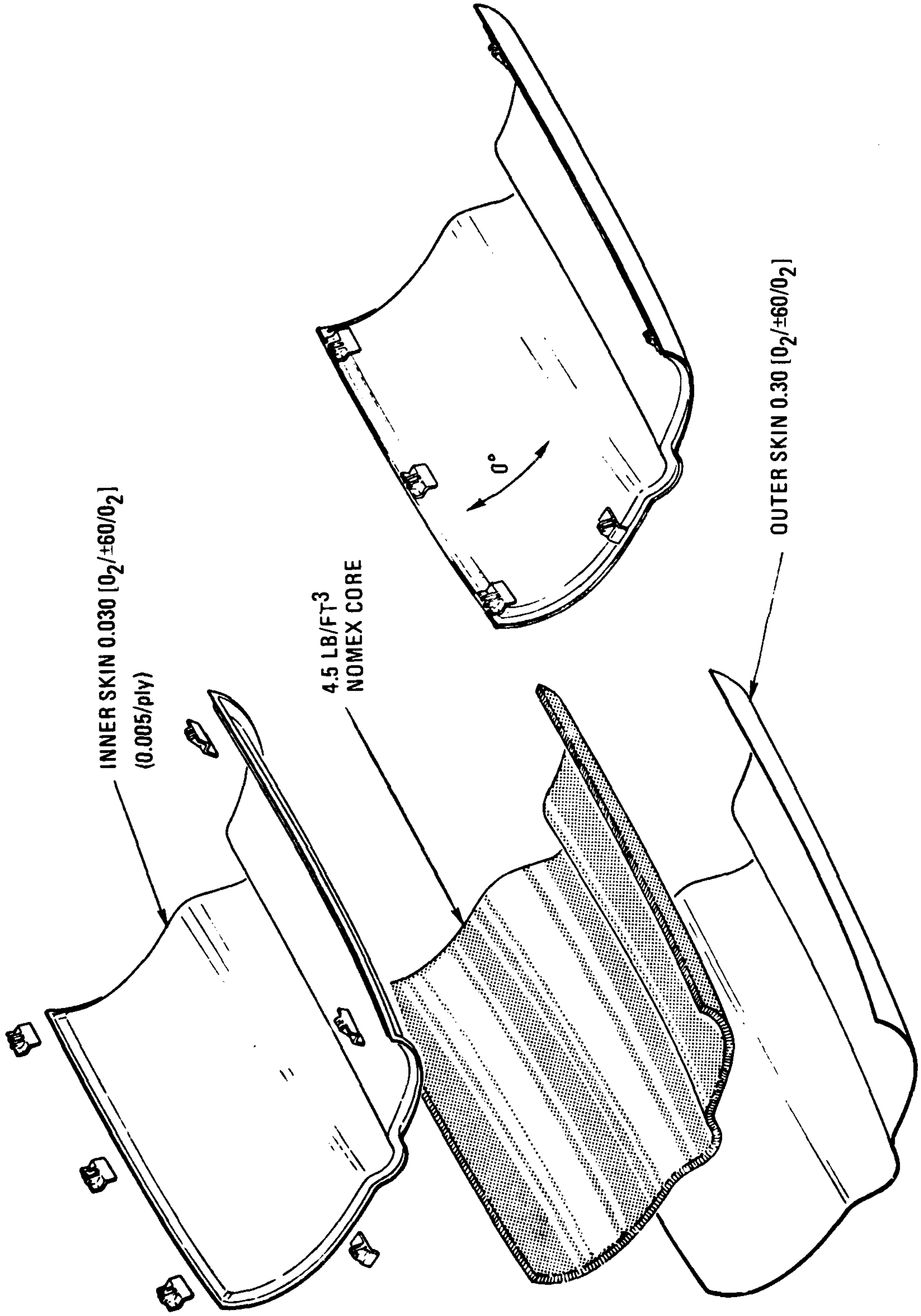


Figure 3-9. Practical Sandwich Door

the inner skin or liner, acting together with the shell, provides the structural load paths for bending and torsional loads. As in the case of the sandwich configuration, hinge, latch, and actuator fittings are conventionally machined aluminum details, bolted to the inner liner.

The skin liner configuration offers the opportunity to tailor bending and torsional rigidity by tailoring the geometry of the liner. In the design proposed, bending rigidity for M_{yy} loading results from two hat-shaped beams — one each on the fore and aft ends of the door. Torsional rigidity results from a combination of shapes. On each outboard edge of the door, a small torque box is created by the shell and liner sill. The central bulge of the door in addition acts as an open section that is capable of torque transmission.

Internal loads were most critical for the door-open case. Jamb beam bending moments in the area of the actuator fitting were the most severe loadings noted, and they created a strength-critical beam. Other beam elements, although necessary to keep deflections under control, are relatively lightly loaded. The same is true of the skin. Loading in the skin is quite light, although skin buckling and panel flutter are critical. Areas under biaxial compression are of concern for buckling.

Deflections under the door-open condition are quite large for the skin/liner configuration as was the case in the sandwich configuration. The free corner of the door deflects 4.1 inches in the z-direction (down) and 1.45 inches in the y-direction (aft). Figure 3-10 shows the configuration and skin layups of the chosen configuration.

3.2.2.3 Comparative Results. Once the designs were established for each configuration, weight calculations were made and the results were compared to a baseline aluminum door. It should be noted that the baseline aluminum door has been changed to configuration matching the graphite/thermoplastic Concept 5a (Table 3-2). This represents a new baseline configuration that more realistically compares the metal and composite designs. Listed in Table 3-2 are the minimum Weight Sandwich Design (4a), the Practical Sandwich Design (4b), and the new Shell/Liner Design (5a), in addition to designs previously presented. The percentage of weight saved is in relation to the new baseline.

3.2.2.4 Tradeoff Summary. Based on the preceding analyses, a decision was made to proceed with the two-piece door as the configuration to be designed and built. This configuration was chosen primarily because it offers a better opportunity to investigate the forming of Gr/TP into a typical complex aerospace structure. Secondarily, it offers the best potential for cost reduction. As summarized previously, the weight saving over a metal door is moderate and comparable to the practical sandwich door. It was recognized that the two-piece door is definitely more of a technical risk than the sandwich door.

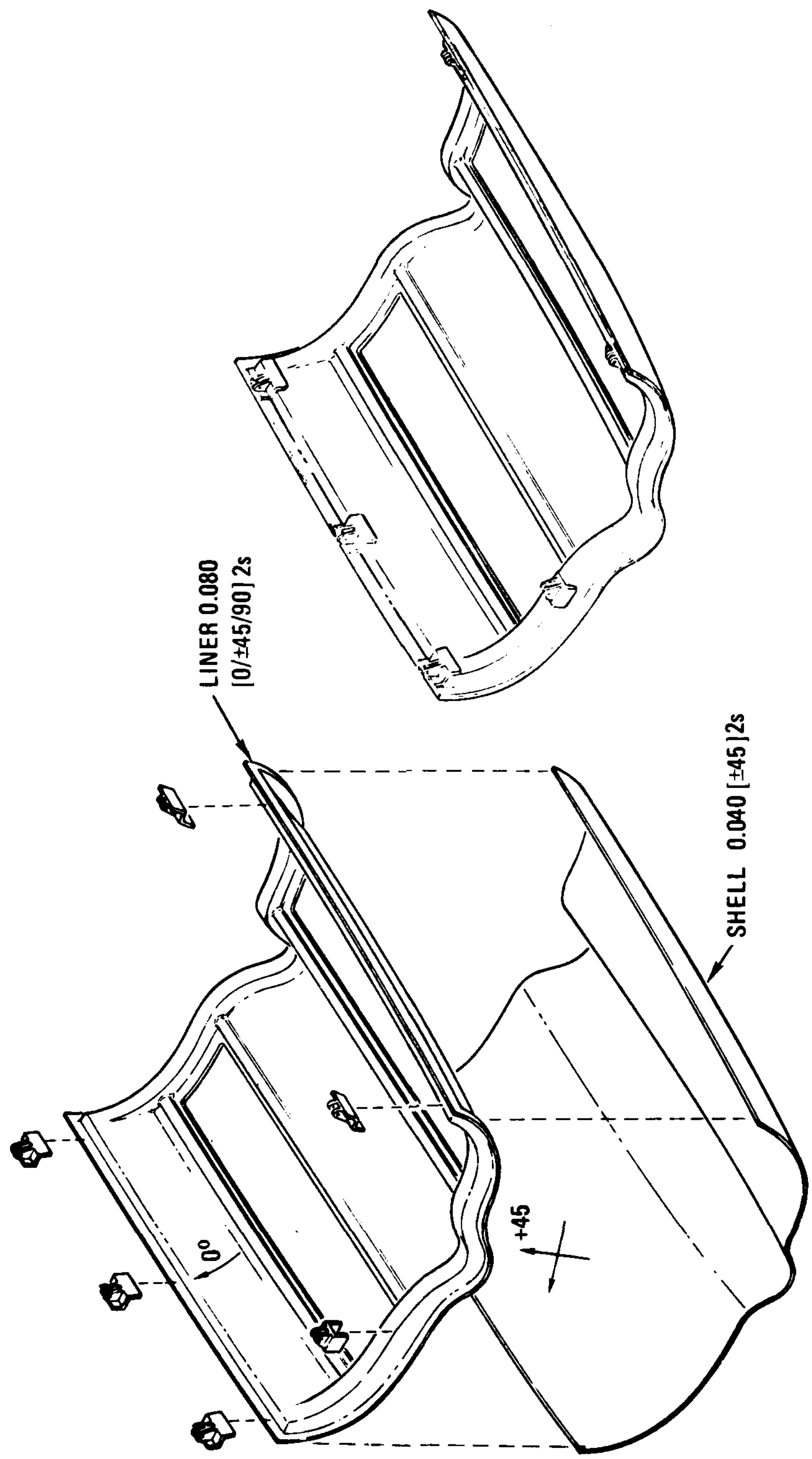


Figure 3-10. Graphite Thermoplastic MLG Door Shell/Liner Construction

Table 3-2. Weight Summary Concept Tradeoff Study, Graphite Thermoplastic Door

CONCEPT		WEIGHT, LB.	WEIGHT SAVED, LB. New Baseline	% WEIGHT SAVED
Metal Door	Original Baseline	17.0	-	-
	New Baseline	18.9		
1.	GRTP Duplicate of original metal Figure 3-3	11	7.9	41.8
2.	Partial Inner Skin Figure 3-4	10.4	8.5	45.0
3.	Full Inner Skin Figure 3-5	10.7	8.2	43.4
4.	Sandwich (Initial Estimate) Figure 3-6	13.4	5.5	29.1
4a.	Sandwich (Maximum Wt. Saving) Figure 3-8	8.8	10.1	53.4
4b.	Sandwich - Practical Figure 3-9	11.6	7.3	38.6
5.	Two Piece (Initial Estimate) Figure 3-7	11.4	7.5	39.7
*5a.	Two Piece - Modified Figure 3-10	13.5	5.4	28.6

*Ref. Paragraph 5-2

SECTION 4

PROCESS DEVELOPMENT

Development of the processes for forming the MLG door was conducted with materials that would meet the size requirements of subelement hardware. This condition enabled the evaluation of the forming process under the most stringent conditions for forming and thereby identified problem areas early so that correction could be made in tooling or methods.

4.1 MATERIAL CONSOLIDATION

Sheet stock produced from A-S/polysulfone prepreg six inches wide produced by E. I. DuPont was used for the fabrication of all parts. The prepreg was laid up in the sizes detailed in Table 4-1 and then consolidated in an autoclave at 600F and 100 psi.

Table 4-1. Main Landing Gear Door Material

Item	Material		
	Dimension	Layup	Thickness
Beam Skin	10" x 45"	$[\pm 45]_{s2}$	.040"
Torque Box Skin	10" x 36"	$[\pm 45]_{s2}$	.040"
Beam Skin Doubler	10" x 10"	$[\pm 45]_{s3}$	.060"
Torque Box Skin Doubler	10" x 36"	$[\pm 45]_{s3}$	.060"
Torque Box Liner	10" x 36"	$[\pm 45/90/\pm 45/90/0_2]_s$	.080"
Beam Liner	10" x 45"	$[\pm 45/90/\pm 45/90/0_2]_s$	.080"
Torque Box Liner Doubler	10" x 36"	$[\pm 45]_s$	.020"
Beam Liner Doubler	10" x 10"	$[\pm 45]_s$	.020"

Processing conditions required that the material be brought to temperature and then immediately cooled to room temperature. No soak time at temperature was required. All the material consolidated in this manner was fully consolidated and exhibited good surface quality.

4.2 SKIN FORMING PROCESS DEVELOPMENT

Two subelement parts were formed to establish the vacuum forming process for the skin: the beam skin, and the torque box skin. The beam skin was formed from 10-inch-wide by 45-inch-long, 0.040-inch-thick material. The torque box skin was formed from 10-inch-wide by 37-inch-long, 0.040-inch-thick material. In both cases the fiber orientation was $[\pm 45]_{2S}$. The forming was accomplished using the full-scale skin panel ceramic tool shown in Figure 4-1.

The ceramic tool was cleaned with solvent, and Frekote 33 release agent was applied. Sheet stock was then held in place using glass tape. Armalon and bleeder cloth were then placed on top of the consolidated sheet. Silicone rubber bagging material was then attached to the ceramic die and vacuum (28 inches of mercury) was applied. The vacuum pressure pulled the flat sheet stock down to the contour of the ceramic tool. Thermocouples were then applied, and the tool was placed in an air oven and elevated to 500F while maintaining vacuum pressure. The tool was then removed from the oven and cooled to below 300F. Vacuum pressure was then released and the formed parts removed. Figure 4-2 shows the skin formed. Initial evaluation indicates that the parts were in the configuration required with full consolidation. It was determined later, however, that it was necessary to use autoclave pressure to form the full-scale skin due to the increase in size over the subelement skin section.

Figure 4-1. Full-Scale Skin Panel Ceramic Tool

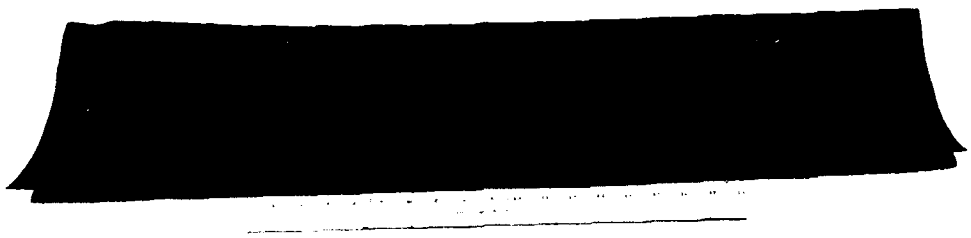


Figure 4-2. Vacuum-Formed Skin Section

4.3 LINER FORMING PROCESS DEVELOPMENT

Vacuum forming of the liner in the same manner as the skin was attempted. However, because of the severe forming requirement of the hat sections, the process could not be used successfully. It was determined that a matched set of metal tools would be required for forming both the subelements and full-size door liner.

The process developed used a matched set of Kirksite dies to form a preform of the door liner. The Kirksite tools were heated in an air oven to 550F, a blank of prepreg material was placed in the female die, and the male punch was then placed on top to form the part in the same manner as if a press were used. When the temperature of the Kirksite reached 300F, the dies were separated and the preformed part was removed. This was required to remove the part without cracking due to the difference in coefficient of expansion between the graphite/thermoplastic and Kirksite. Final forming of the part was then accomplished using the ceramic tool and 80 psi autoclave pressure at a temperature of 550F.

4.4 BULKHEAD FORMING PROCESS DEVELOPMENT

The process established for forming bulkheads used aluminum tooling in conjunction with vacuum bagging and autoclave pressure. Blanks of material were located on the

tool and a silicone bladder was clamped over the part. Vacuum pressure was applied and the part was heated in an autoclave to a temperature of 525 F. When temperature was reached, the vacuum was vented to atmosphere and 80 psi pressure was applied. The part was then cooled to below 300F. under pressure before removal. The process proved to be completely satisfactory for the forming of bulkheads.

SECTION 5

COMPONENT DESIGN AND ANALYSIS

5.1 DOOR DESIGN

The door configuration established in the design studies was the starting point for the component design. A more detailed analysis of the door structure revealed the need for several modifications to the door configuration. These included:

a. Moving the stiffening beads to the inflection points of the curves.

b. Increasing the size of the hinge sill beam to form a more effective torque box.

c. Providing doublers over the torque box area on both the skin and liner.

d. Increasing the height of the actuator beam locally near the hinge.

e. Increasing the height of the rear beam.

The door is formed in two parts, a liner and the skin. The liner is a pseudoisotropic laminate 0.08-inch thick. The layup is $[\pm 45/90/\pm 45/90/0_2]_S$ for the liner, and the skin is 0.040-inch-thick, ±45° laminate. In areas that are reinforced, ±45° plies are used. The skin doubler is 0.080 inch and the liner doubler is 0.040 inch.

When the door was investigated for the local loads applied by the hinges, latches, and actuator fittings, it was determined that several modifications were indicated. These included the addition of formers in the area of the latches and hinges to preclude deformation of the skin. In addition, a small metal plate was added to the underside of the forward beam under the actuator fitting to increase the margin of safety on the blind nuts that attach the fitting.

It was also decided that the center hinge would be deleted as the loads on it were negligible. This action also simplifies rigging of the door since it is no longer necessary to axially align hinge points.

The final door design and details are shown in Figures 5-1 through 5-9.

5.2 WEIGHT COMPARISON

In keeping with the philosophy established in the design study, the comparison baseline metal door was assumed to be similar in design to the latest composite configuration. Because the baseline design was changed, the weight comparison listed here differs from those shown shown in the Section 3. The weight of the composite door was calculated to be 13.46 pounds. The corresponding metal door was determined to weigh 18.9 pounds. This is a weight saving for the composite door of approximately 29%.

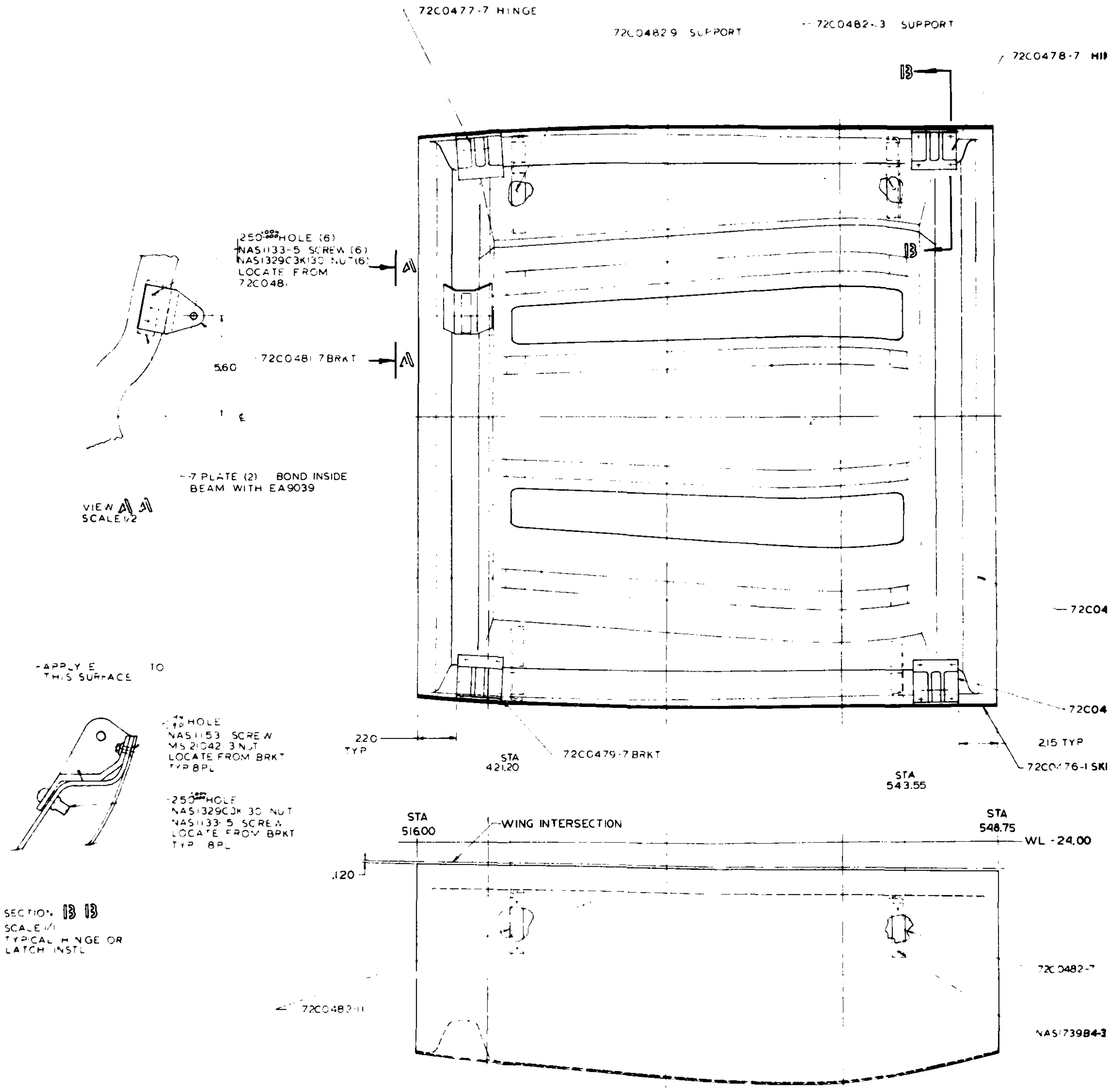
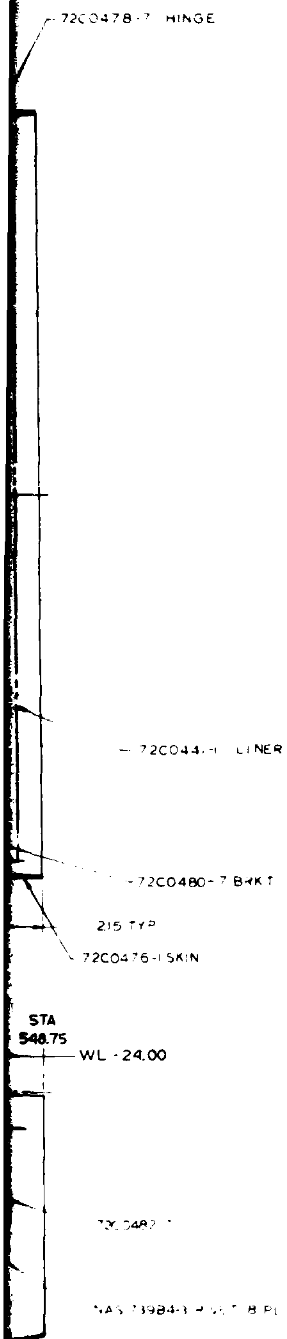
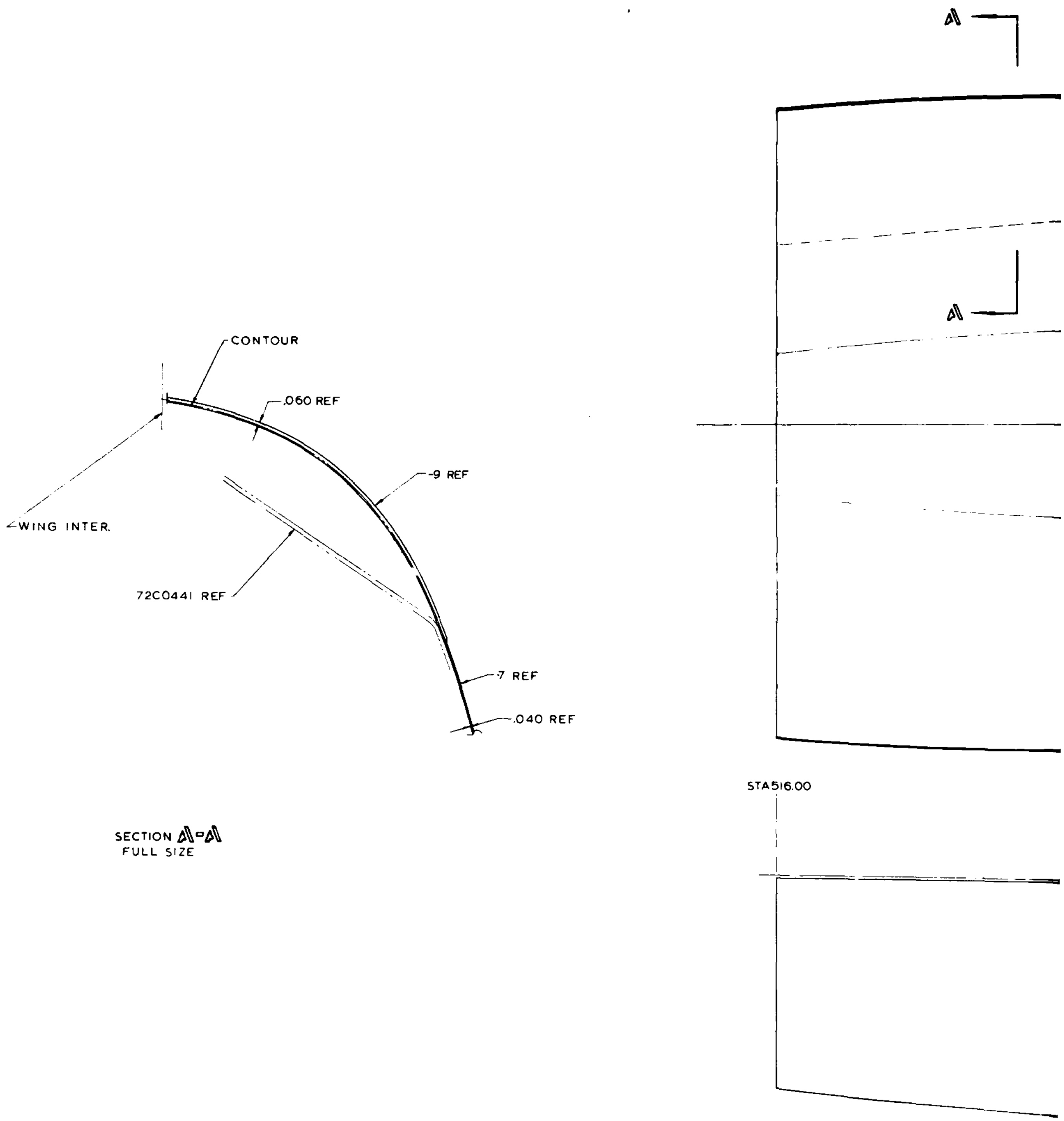


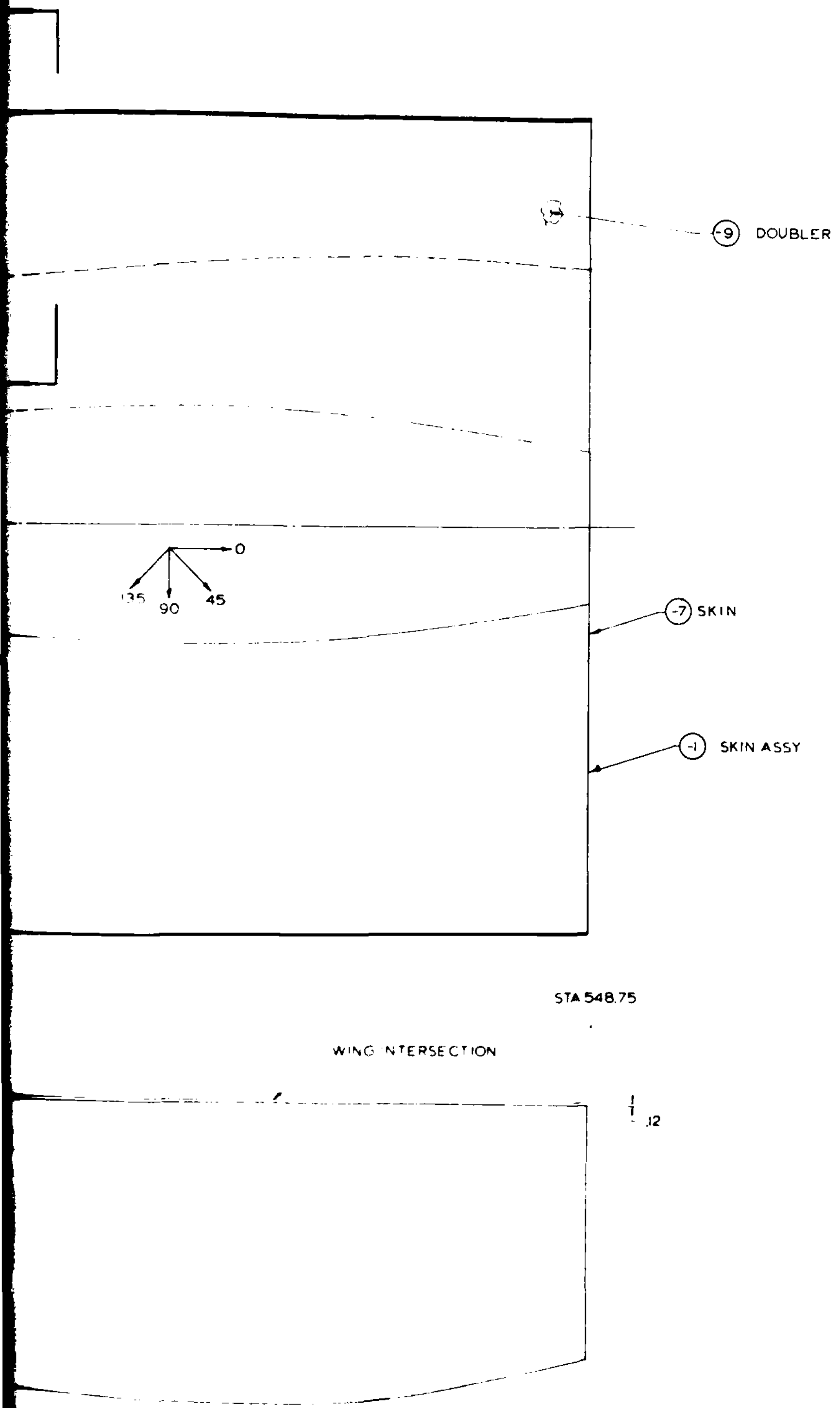
Figure 5-1. Graphite Thermoplastic Main Landing Gear Door Assembly


72C0478-7 HINGE
72C0480-7 BRKT
2.15 TYP
72C0476-1 SKIN
STA
548.75
WL -24.00

Assembly



SECTION A-A
FULL SIZE



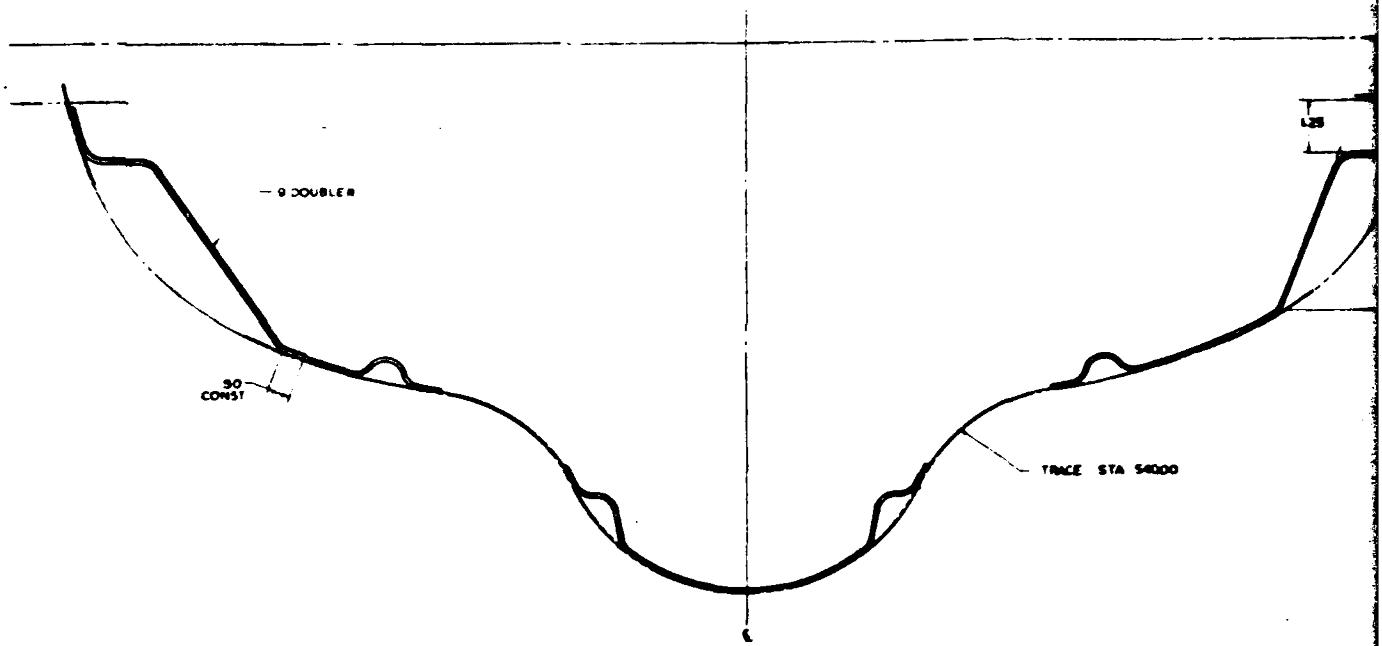
1 FOR CONTOUR SEE 72C0402.

NOTES:

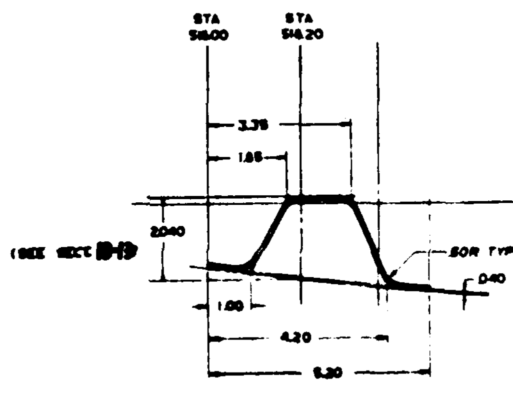
1	-9	DOUBLER	10x45x[±45]$_{S3}$(.060) A-S/P1700
1	-7	SKIN	36x45x[±45]$_{S2}$(.040) A-S/P1700
	PART NO	NAME	STOCK SIZE, MATERIAL
-1			
REQ PER ASSY			

PARTS LIST

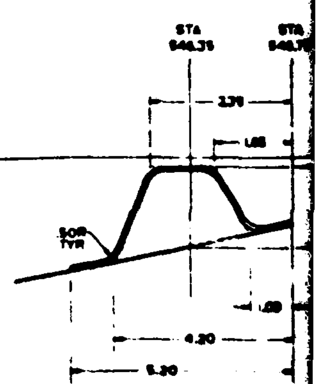
Figure 5-2. Door Skin



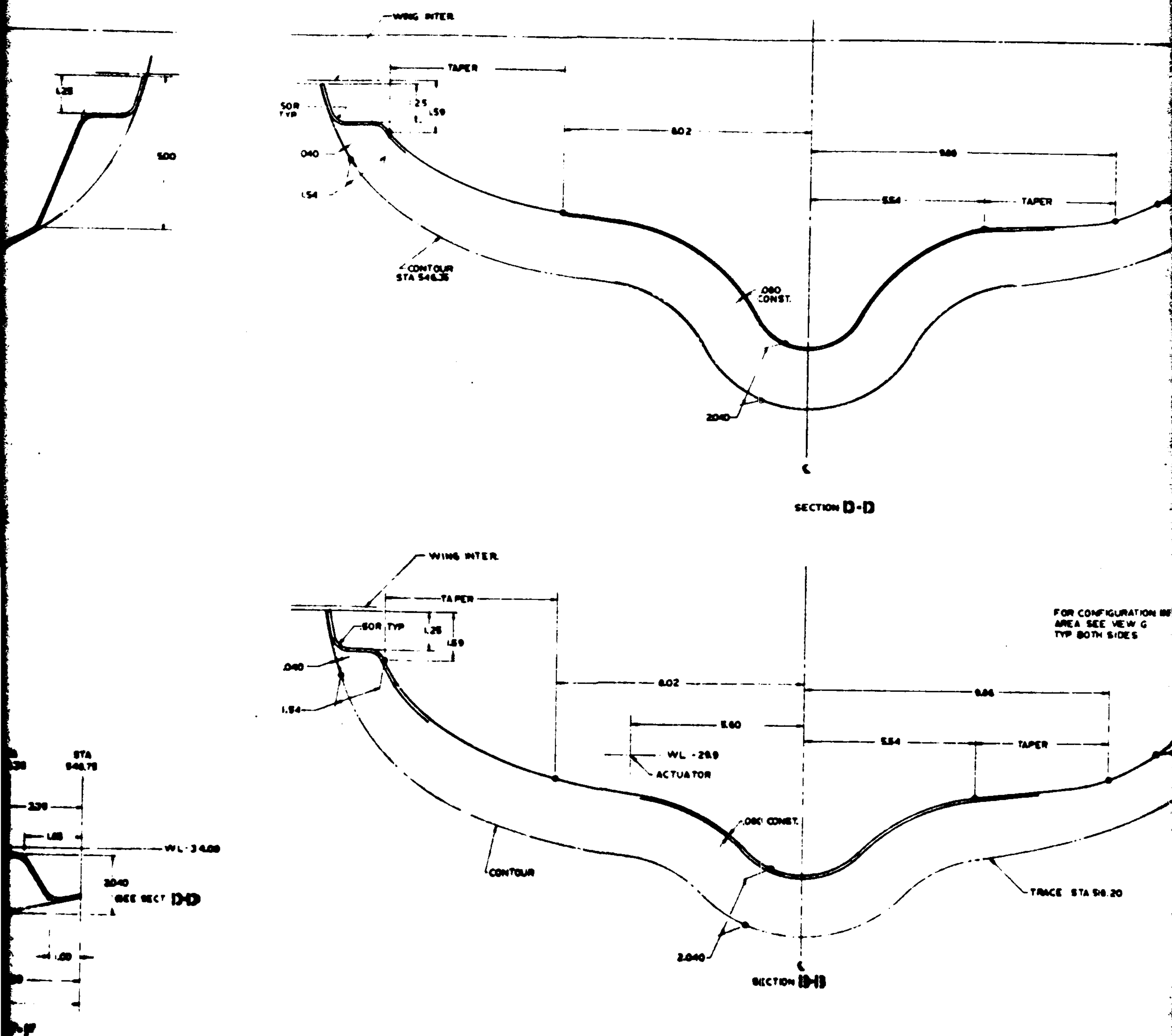
SECTION C-C



SECTION E-E



SECTION F-F


WING INTER
TAPER
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1.25
.50R TYP
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1.54
8.02
9.86
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TAPER
CONTOUR
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.080 CONST.
2.040
SECTION D-D
WING INTER
TAPER
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8.02
9.86
5.60
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ACTUATOR
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TYP BOTH SIDES
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CONTOUR
TRACE STA 516.20
2.040
1.00

2

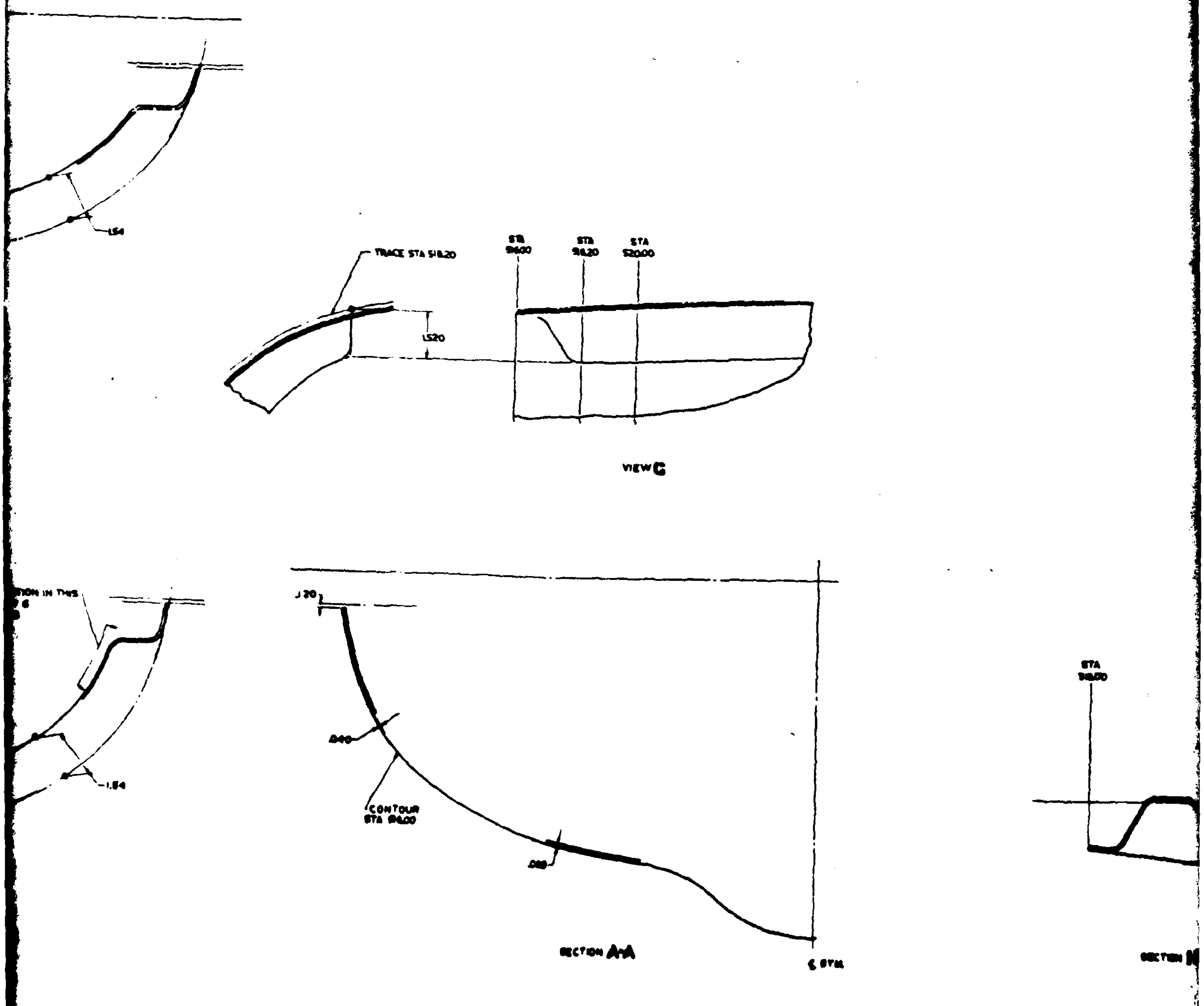
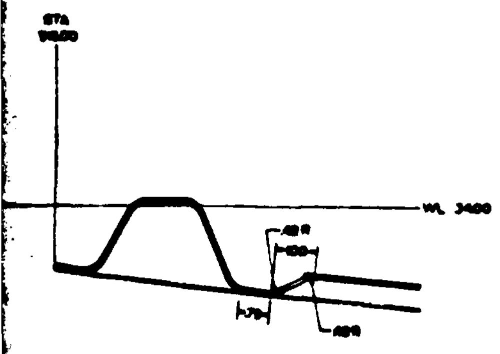


Figure 5-3. Door Liner Details

3



SECTION H-H

Liner Details

1 4

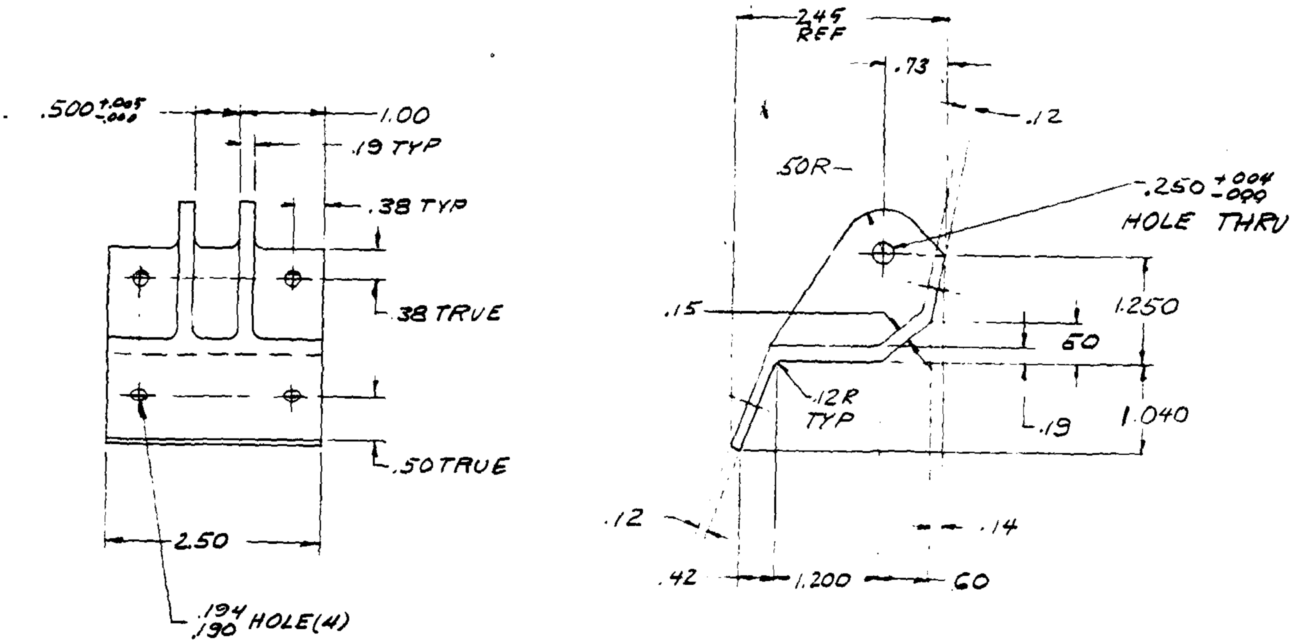


Figure 5-4. Main Landing Gear Door Forward Latch Bracket

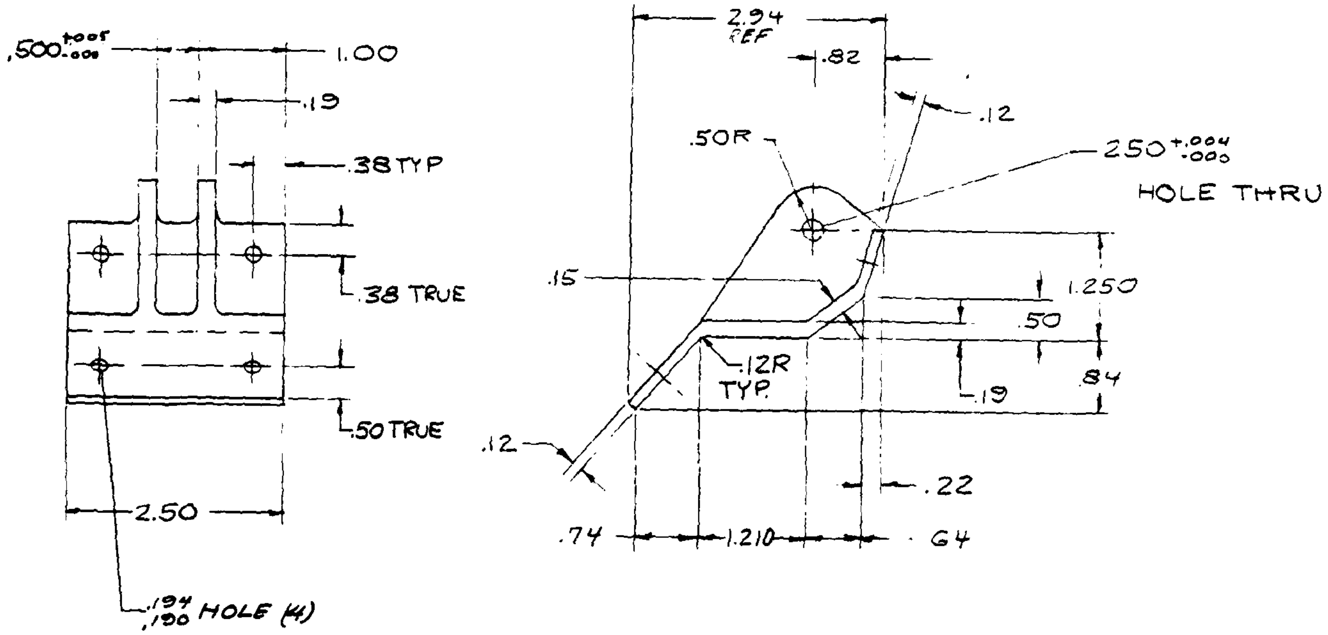


Figure 5-5. Main Landing Gear Door Aft Latch Bracket

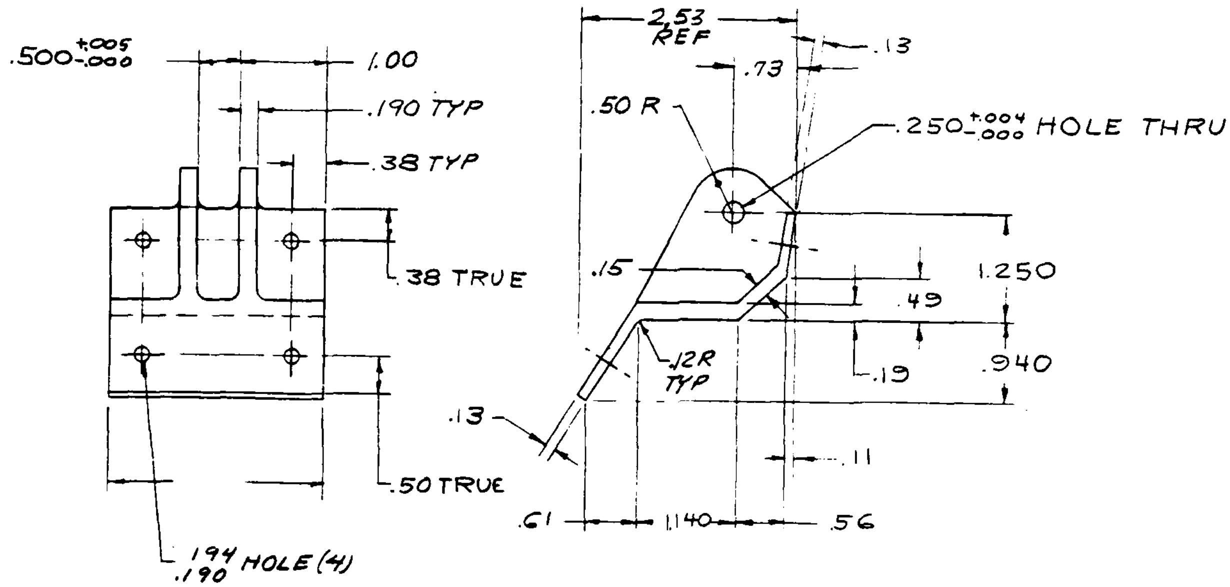


Figure 5-6. Main Landing Gear Door Front Hinge

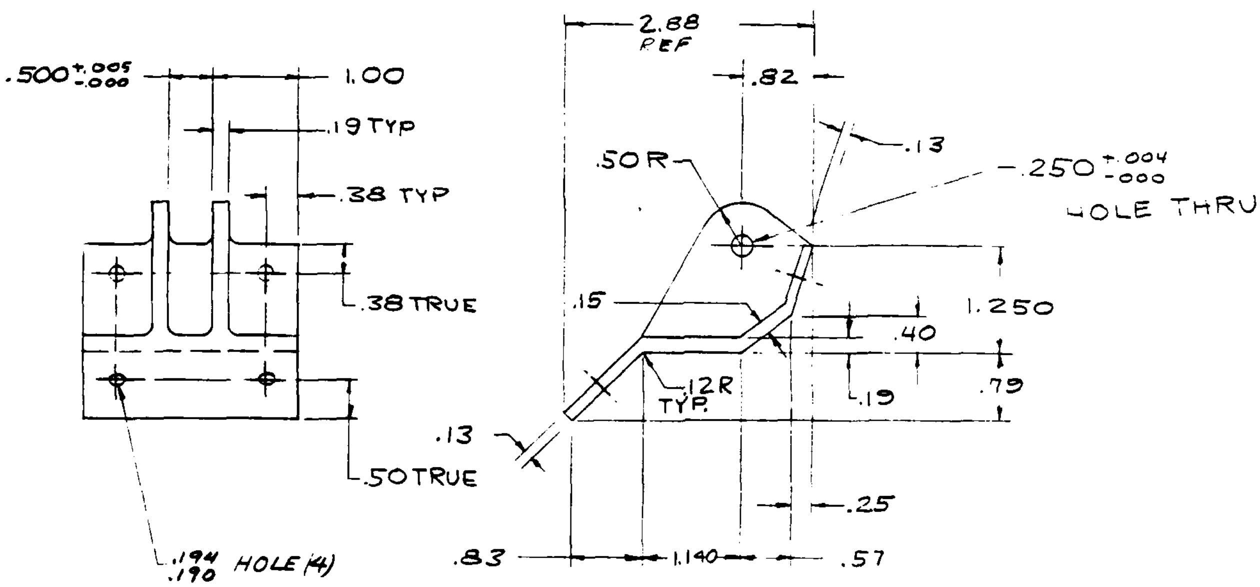


Figure 5-7. Main Landing Gear Door Rear Hinge

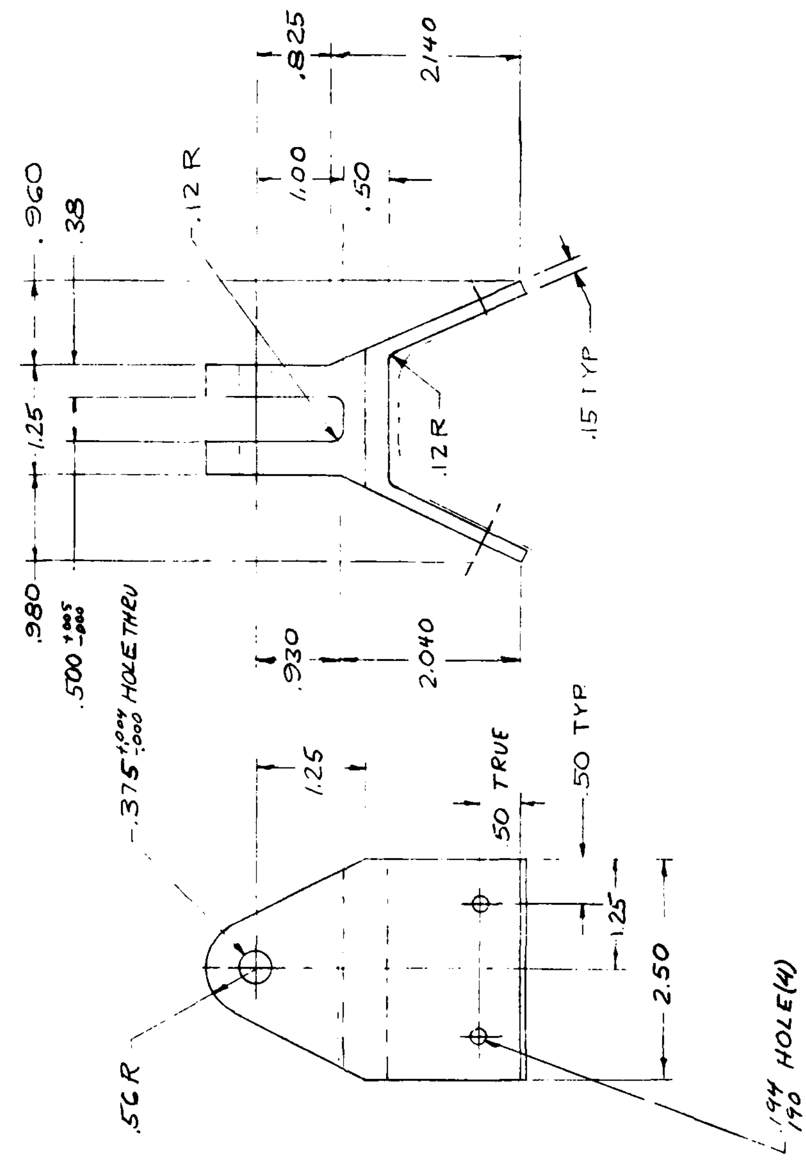


Figure 5-8. Main Landing Gear Door Actuator Bracket

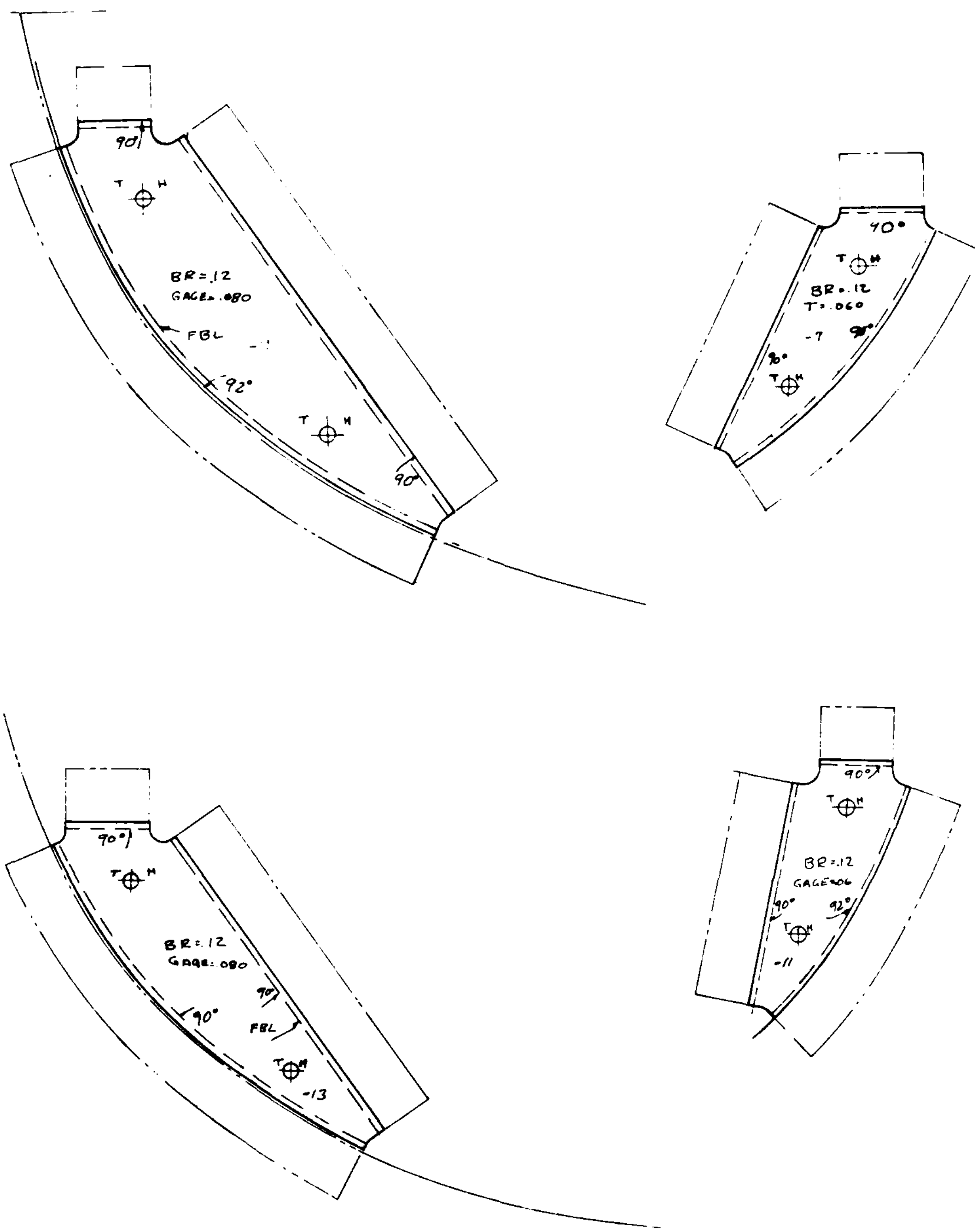


Figure 5-9. Door Hinge and Latch Supports

5.3 COMPONENT ANALYSIS

A structural analysis for the principal structural members of the main landing gear door is presented. The analysis is made for the flight load condition with the door open. This condition is considered more critical than the loadings with the door closed, since for this condition, latches will provide additional support.

The mechanical properties used for the graphite/thermoplastic materials were originally derived from the unidirectional laminate properties for intermediate strength graphite/epoxy. The properties were later proved to be essentially the same.

$$E_{11} = 17.0 \times 10^6 \text{ psi}$$

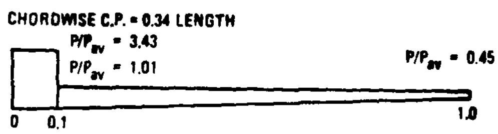
$$E_{22} = 1.7 \times 10^6 \text{ psi}$$

$$\mu_{12} = 0.21$$

$$G_{12} = 0.65 \times 10^6 \text{ psi}$$

These properties were input into the laminate analysis program (SQ5) to obtain the appropriate values for the laminates used.

The design loads were determined as a step function of applied pressure. The design loads, although not exactly the true pressure distribution, do represent a typical condition. The total load of 1532 pounds (limit) is preserved along with the location of the center of pressure. The pressure distribution is given in the sketch.



CHORDWISE DISTRIBUTION

The door is formed in two parts: a liner and the skin. The liner is a pseudoisotropic laminate of 0.08-inch thickness. The fiber layup is $[\pm45/90/\pm45/90/0_2]_S$ for the liner, and the skin is an 0.040-inch-thick laminate of ±45° lamina. In areas that are reinforced, ±45° plies are used.

The analysis proceeds to examine the door under the applied pressure loads. The skin panels are analyzed for stability, and the hoop loads in these panels are the loads on the beams running forward and aft. Then, these beads are analyzed for strength and stability along with the major jamb beams of the door. The torque box analysis follows, showing the moment diagrams for the ribs. The torque box components are analyzed for strength and stability. The analysis concludes with an examination of all fittings and attachments.

The stress analysis is summarized in Table 5-1, which lists the minimum margins of safety for critical portions of the door.

Positive margins of safety are shown on all portions of the door with the minimum margin shown in the torque box stability analysis and the forward beam analysis in areas of high curvature.

Table 5-1. Summary — Minimum Margins of Safety

Item	Loading		M. S.
Unsupported Skin	Pressure		Large
Longitudinal Bead #1	Compression		+0.82
Longitudinal Bead #2	Compression		+0.85
Longitudinal Bead	Torsion		Large
Forward Beam at Actuator Fitting	Bend in Compression		+0.97
Forward Beam at Actuator Fitting	Shear		+0.26
Forward Beam next to Fitting	Bending	Liner	+0.21
Forward Beam next to Fitting	Bending	Skin	+0.02
Torque Box Upper Strip	Shear		+2.0
Torque Box Liner Panel	Shear Strength		Large
Torque Box Liner	Shear Stability		+0.45
Torque Box Skin	Shear Stability		+0.22
Actuator Fitting	Bearing in Liner		+0.17
Hinge Fitting	Pin Bending		+0.5

SECTION 6

TOOL DESIGN AND FABRICATION

Tool design studies were conducted to determine the lowest cost methods for fabrication of tools for forming graphite/thermoplastic to the configurations required for both the MLG door skin and MLG door liner. The initial concept chosen was to fabricate cast ceramic tools and then form parts using a silicone rubber bag with vacuum pressure, in an oven. Problems arose that required a low-cost method of fabricating matched metal tools to be developed. Final tooling for the MLG door used a combination of cast ceramic and matched metal to achieve the configurations required after forming.

6.1 TOOL CONCEPT

At completion of the trade study to determine the configuration of the MLG door, a review was conducted to determine the type of tooling to be used in fabrication of the door. Simple ceramic tooling was chosen with pressure to be applied by a vacuum bag and, if necessary, additional pressure applied by use of an autoclave. Designs for the tools are shown in Figures 6-1 and 6-2. Later it was determined that a set of matched metal tools would be required for preforming the MLG liner. The low-cost concept to produce this tool was to cast the tool from Kirksite and to use the weight of the punch as the force necessary for forming.

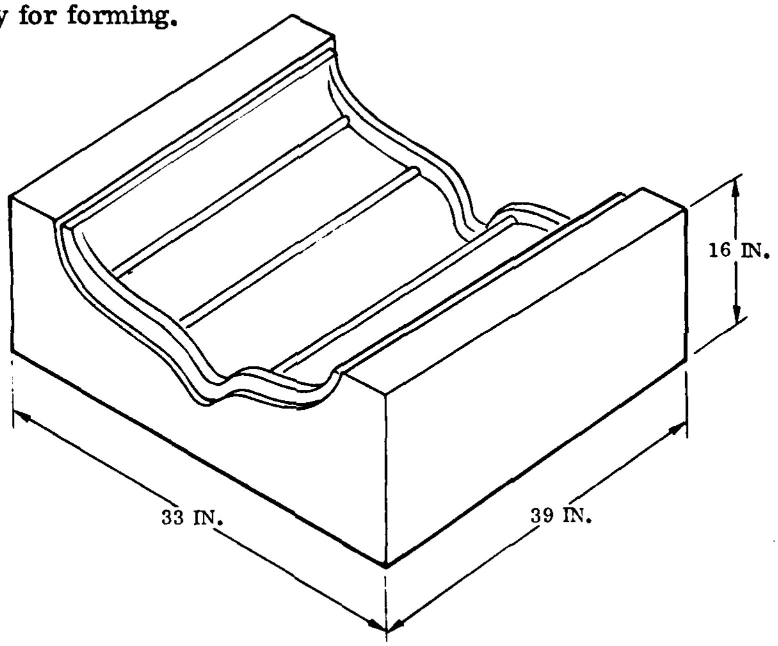


Figure 6-1. MLG Liner Tool

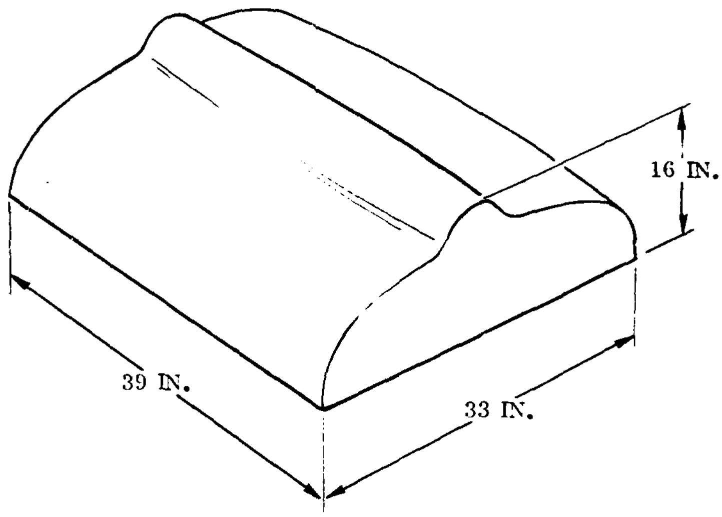


Figure 6-2. MLG Skin Tool

Assembly tools for the MLG door were not deemed necessary since matching contours and trim lines could be used for locating the detail parts. Layout techniques could also be used for locating the hinges and latch, which also eliminated the need for assembly tools.

6.2 TOOL FABRICATION

6.2.1 PLASTER MASTER MODEL FABRICATION. Station plane line drawings of the MLG door skin were used to fabricate a male plaster master model shown in Figure 6-3.

A female plaster cast was then taken from the male skin master model and used to model the MLG door liner model shown in Figure 6-4. Fabrication of the plaster master models in this manner assured that mating surface to be adhesive bonded would match during final assembly of the detail parts.

6.2.2 CERAMIC TOOL FABRICATION. Tools for vacuum forming of the MLG door skin and MLG door skin liner were fabricated from 195 lb/cu ft castable fused silica.

Plaster casts were taken from the master models and forwarded to AeroSpex Corp., Chula Vista, California, for casting of the ceramic tools.

Figure 6-3. Male Plaster Master Model

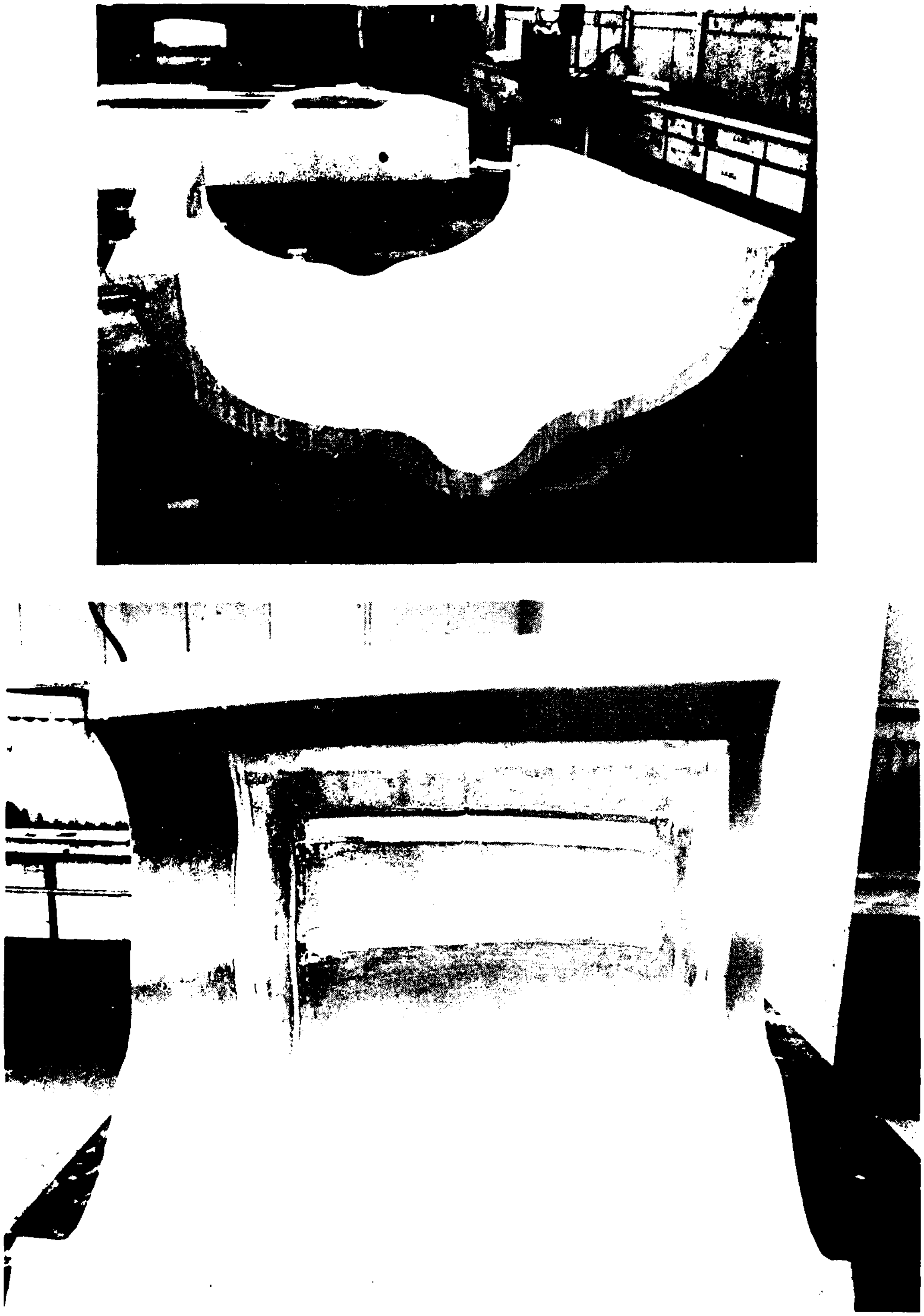


Figure 6-4. Door Liner Plaster Master (female)

Casting setup of the ceramic tools was accomplished by placing side boards on the plaster cast and inserting a six-inch-diameter tube through the length of the setup. The tubes were used to reduce the quantity of ceramic and thus the weight of the ceramic tools. The surface of the plasters and the sideboards were then waxed with release agent and the ceramic mixed and poured. A single mix of ceramic was used for casting each tool so that no interfaces were present to reduce strength. After casting, the tool was covered with plastic and given a 72-hour, high-humidity cure. At completion of the high-humidity cure, the sideboards were removed and the tools were given a 72-hour, room-temperature cure. At completion of the room-temperature cure, the tool was separated from the plaster pattern and given a 72-hour cure at 350F. The elevated temperature cure drives off the moisture giving final set to the ceramic. Figure 6-5 shows the completed ceramic tools after casting.

After receipt of the ceramic tools from Aerospex Corp., the surfaces were cleaned with Freon-TF and the spray coated with PYRE-ML for sealing. The PYRE-ML was cured by placing the tools in an oven and elevating the temperature to 500F for 10 hours. Figure 6-6 shows the completed ceramic tool for the MLG door skin.

6.2.3 METAL TOOL FABRICATION. Tools for the four bulkheads were machined in the same manner as form blocks for hydroforming of metal. Each bulkhead tool was rotor-formed machined from a vellum and then mounted on an aluminum plate. A vent hole for pulling a vacuum was machined into the baseplate to facilitate forming in an autoclave. An aluminum clamping plate was machined to hold the rubber bladder during forming. Figure 6-7 is a sketch of the bulkhead tooling.

A set of matched metal dies for preforming the MLG door skin liner were fabricated using a low-cost approach. A set of matched Kirksite dies was cast using the ceramic final form tool as the master pattern for final configuration.

A plaster splash was taken from the ceramic tool and cut to make allowances for the Kirksite shrink after casting. After clean-up of the face of the female Kirksite die, 0.100 inch of asbestos was glued to the face using water soluble glue. The female Kirksite die was placed in a die box heated to 500F, and the male punch was cast directly into the finished female Kirksite die. After cooling, the dies were separated and the faces were cleaned and polished. Figure 6-8 shows the complete, matched-set, Kirksite tool. The advantage of this system is that the costly matching of complex contours is eliminated while at the same time achieving a close-tolerance forming tool.

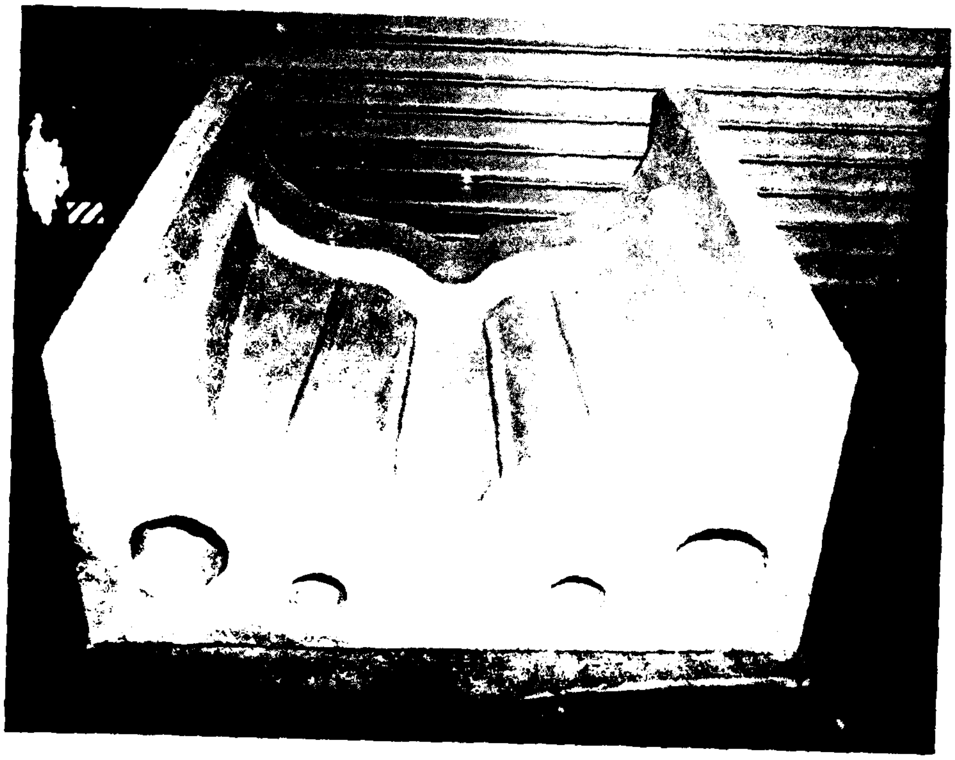


Figure 6-5. Completed Ceramic Tools after Casting

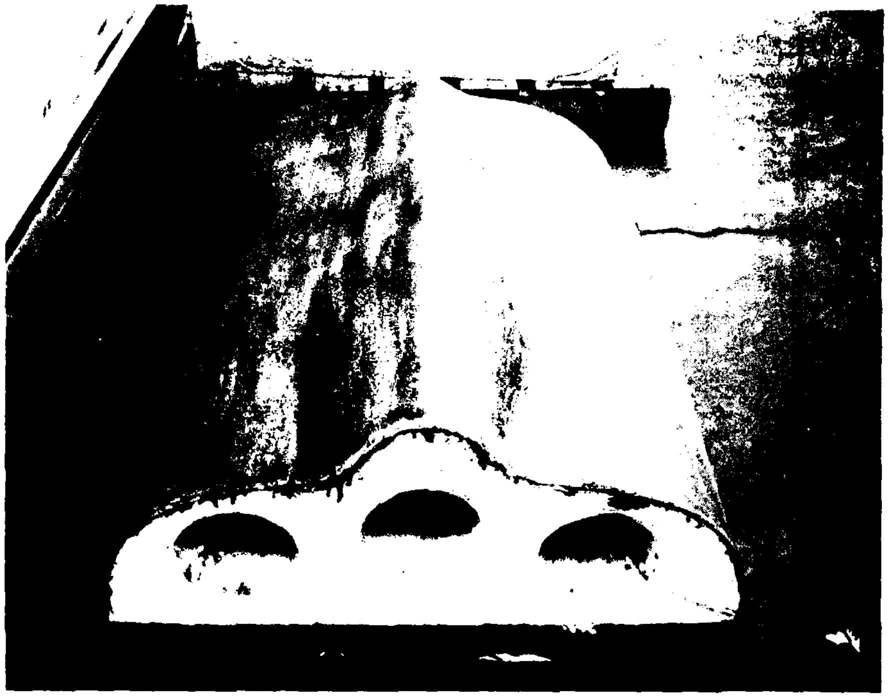


Figure 6-6. Completed Ceramic Tool for MLG Door Skin

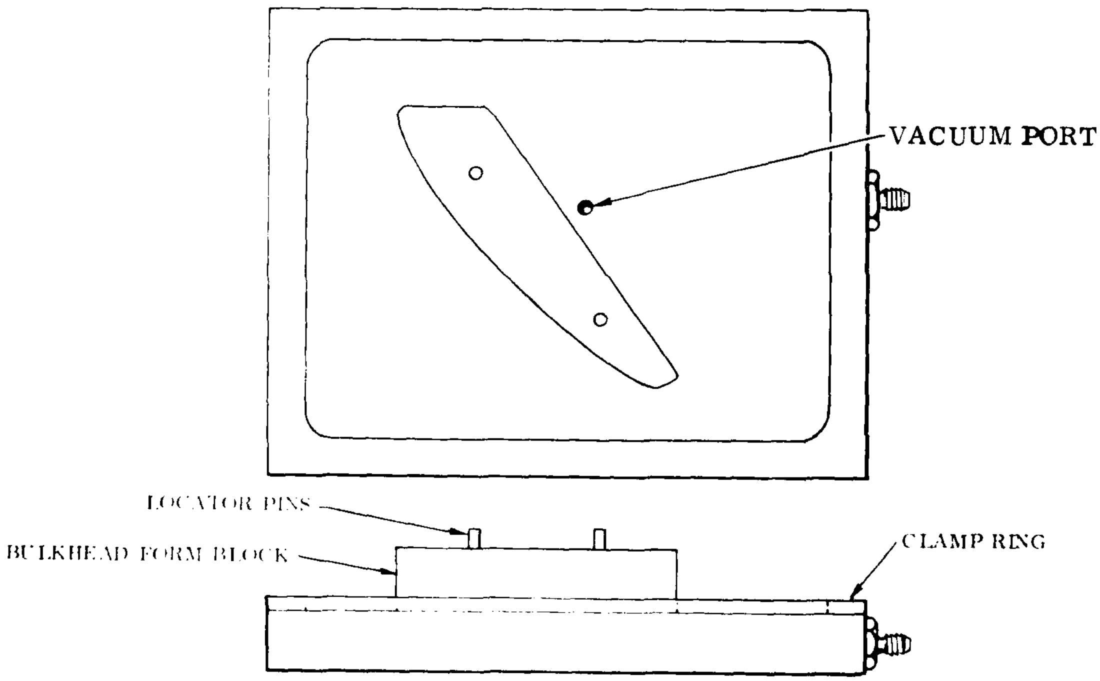


Figure 6-7. Bulkhead Form Tool

Figure 6-8. Complete, Matched-Set, Kirksite Tool

SECTION 7

SUBCOMPONENT DESIGN, ANALYSIS, FABRICATION, AND TESTING

7.1 IDENTIFICATION OF SUBCOMPONENTS

As the design study and the component design and analysis progressed, several areas of concern were apparent. These were the attachment of the metal hinges and fittings to the composite door, the strength of the forward or actuator door beam, and the torque box area of the door.

7.2 FITTING ATTACHMENT SUBCOMPONENTS

One area of concern in the final design of the subcomponent and door component was the attachment of the hinge fittings and actuator fittings to the door. The configuration of the door liner necessitated the use of a blind nut, or captive nut, mounted on the inside or hidden side of the liner, to which the fasteners could be attached. A review of currently available blind nuts was made, and an evaluation of two types was conducted. The first type investigated was a high-shear, blind, pressed nut available in two types. One has a very thin head and the other is a true flush-type fastener. Examples of these nuts were obtained from High-Shear Corp., installed into a 0.070-inch-thick crossply graphite/polysulfone laminate using standard production installation tools. Figures 7-1 and 7-2 show installed fasteners. The installed fasteners were tested by inserting a bolt against a spacer and torquing it to test the connection between the fastener and the sheet. These initial tests have indicated the feasibility of this type of fastener. The installation method used for these blind nuts in the thermoplastic material was identical to that used for normal aluminum construction.

Another type of blind fastener, supplied by Goodrich Corp., utilizes a small key to prevent rotation of the fastener in the sheet. This fastener was used in two of the bolted joint specimens.

Four bolted joint specimens were fabricated to test the strength of the joints between the door fittings and the door. Figures 7-3 and 7-4 show the completed specimens. Two specimens utilize countersunk screws attaching the composite to a metal strap while the other two utilize blind nuts set into the composite sheet and simulate the joint between the hinges and latches and the door liner.

The four specimens were tested in a Universal test machine. The two blind nut specimens failed in bearing and shearout of the blind nut in the composite. The loads at failure were 1320 and 1540 pounds. The maximum load required for such a fastener on the door is approximately 1250 pounds at the actuator fitting.

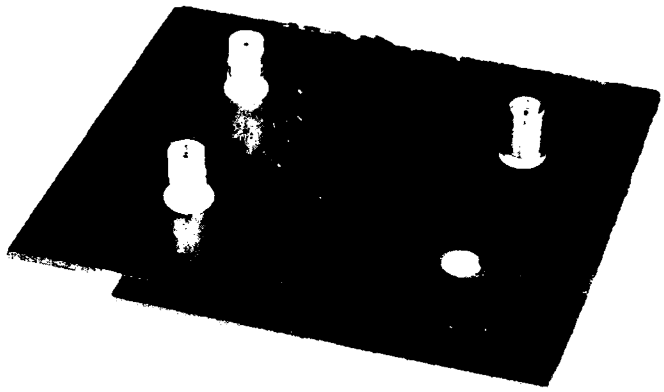


Figure 7-1. "High-Shear" Blind Press Nuts Installed in Graphite/Thermoplastic Material (Rear View)

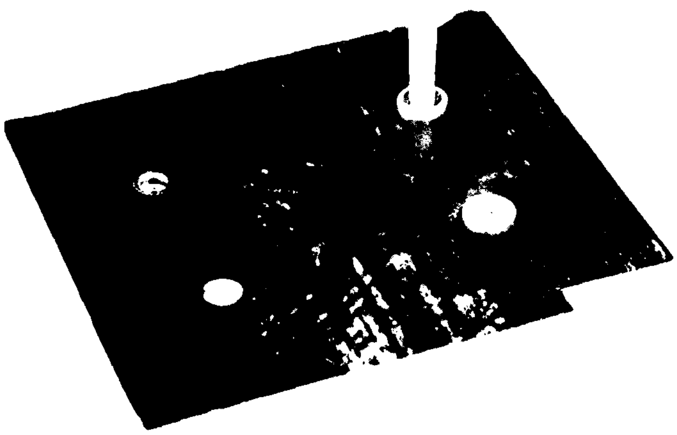


Figure 7-2. Blind Press Nuts, Front or Visible Side. (Flush type on the left, semiflush type on the right)

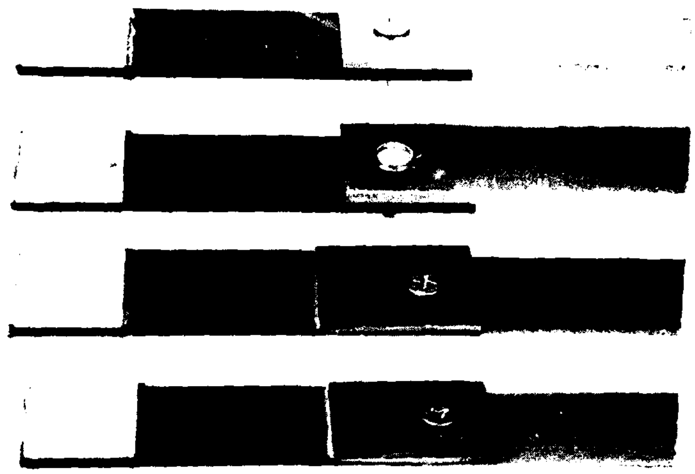


Figure 7-3. Bolt Specimens

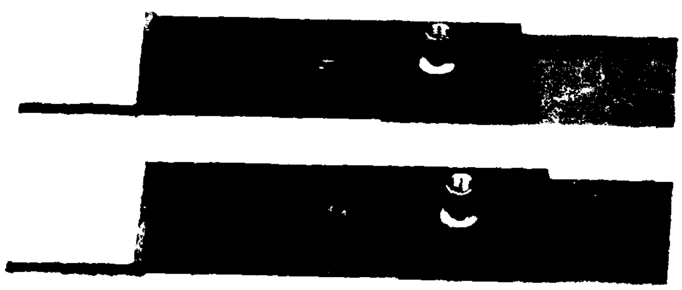


Figure 7-4. Bolt Specimens with Blind Nuts

The countersunk bolt specimens failed by combined loading of the bolt through the first thread as a result of a prying action. Bearing failure of the aluminum and composite was also present due to rotation of the bolt. The failure load of the two specimens was 2100 and 2125 pounds. The maximum load for this type of fastener is approximately 990 pounds at the forward hinge fitting.

Figures 7-5 and 7-6 show the specimens after testing.

The analysis showed that the attachment of the actuator fitting to the forward beam was marginal. Two bolts were added to the actuator fitting and two .015 thick corrosion resistant steel backup plates were bonded inside the door beam to increase the bearing strength of this joint.

7.3 BEAM AND TORQUE BOX SPECIMEN

The subcomponent specimens were intended to serve two purposes. The primary purpose was to serve as process development specimens and secondly to verify the strength of critical structural areas. Specimens were to be fabricated on the complete component tools, using only a portion of the tool. The first of these two specimens consisted of the side area of the door along the hinge line. It was planned to use this specimen for manufacturing development purposes and not to test it structurally. The second specimen consisted of the forward frame of the door including the actuator fitting. This specimen was structurally tested to verify the strength of this critical element. It was planned that drawings of the subcomponent specimens not be made but that the component's configuration be documented by photographs of the completed specimens. This simplification was possible because the configuration of the complete door specimen was documented, and the subcomponent specimens were built identical to the total component.

The torque box specimen was fabricated in detail form but not assembled.

Forming and assembly of the forward beam subelement specimen was accomplished in the same manner as the full-scale MLG door with one exception. Pressures during forming did not exceed 15 psi on the skin and liner subelement detail parts. Only vacuum pressure was used during the forming operations. The bulkheads were formed in the autoclave and were formed with 80 psi pressure.

7.3.1 <u>SUBELEMENT SKIN FORMING.</u> The skin for the door subelement was formed from consolidated material. Prepreg tape was laid up and consolidated in an autoclave at 600F and 150 psi pressure.

The consolidated material was then located on the full-scale ceramic tool and vacuum bagged in place using silicone rubber. The tool was placed in an air oven and elevated to 525F. After reaching temperature the tool was removed from the oven and allowed to cool below 300F before removing the vacuum.

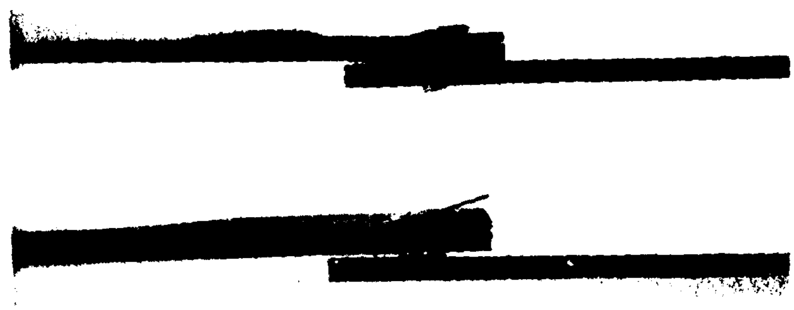


Figure 7-5. Countersunk Bolt Specimen After Testing
(Note that the nut end of the bolts have been pried off.)

Figure 7-6. Blind Nut Joint Specimen

(Both failures initiated as bearing failures of the nut in the composite. The technician continued to apply load to the lower specimen and a shearout failure resulted.)

Figure 7-7 shows the formed subelement skin.

Figure 7-7. Subelement Skin Specimen

7.3.2 SUBELEMENT LINER BEAM FORMING. Forming of the liner beam was performed on the Kirksite tooling. The matched set of Kirksite dies was placed in an air oven and heated to 550F. The die set was then removed from the oven, opened, and unconsolidated material was placed in the lower die. Unconsolidated material was used to facilitate easy movement of the fiber. The punch was then lowered in place, preforming the beam section. When the die set had cooled to 300F, the punch was raised and the beam section was removed. Final forming was accomplished in the female portion of the Kirksite die set, using an overpress fabricated from silicone rubber with vacuum pressure. This was required because of unrepairable damage to the ceramic tool during removal of the full-scale liner. The preformed beam section was located on the female Kirksite, the overpress was put in place, and the part was vacuum bagged using Kapton film. The entire assembly was then placed in an air oven and heated to 550F while maintaining vacuum pressure on the part. After reaching temperature the tool was removed from the oven and allowed to cool under vacuum pressure to 300F. The part was then removed.

7.3.3 SUBELEMENT BULKHEAD FORMING. Bulkheads for the subelement were formed in the same manner as bulkheads for the full-scale MLG door. Blanks of consolidated material were located on the form tool, a silicone rubber bladder was clamped over the tool, the tool was placed in an autoclave and raised to 525 F, and pressure of 80 psi was applied. The formed bulkhead was then cooled to below 300F under pressure before removal from the autoclave. Two bulkheads for the subelement beam were formed in this manner. Trimming operations were accomplished with a bandsaw followed by filing to the part trim line.

7.3.4 SUBELEMENT DOOR LATCH AND HINGES. The subelement door latch and door hinges were machined from 2024-T851 aluminum using conventional machining methods.

7.3.5 SUBELEMENT ASSEMBLY. Assembly of the subelement beam was accomplished by adhesive bonding. Hysol AE 9309 room temperature curing adhesive was used throughout. The bulkhead and 0.010-inch aluminum shims for the latch were first bonded to the beam section and allowed to cure. The skin of the subelement was then bonded to the beam bulkhead subassembly. Pressure during the bonding was provided by vacuum bagging the assembly. After a 72 hour cure, the assembly was removed from the vacuum bag and final trimmed to trim lines previously laid out on the part. The door latch and hinges were then located and assembled to the beam using conventional fasteners. In addition, each bulkhead was riveted to the skin with two rivets. Figure 7-8 shows the completed sublement beam section.

7.4 SUBELEMENT BEAM TEST

The subelement beam was tested as shown in Figure 7-9. The objective was to successfully apply a force P of 1,330 pounds in order to produce the ultimate bending moment of 6,000 in.-lbs. at the door centerline. The beam only proved capable of carrying an applied load of 840 pounds. It was therefore concluded that the completed door construction must include rows of rivets running parallel to and on either side of both the forward and aft beams. These rivets were intended to prevent the type of delamination experienced in the subelement testing.

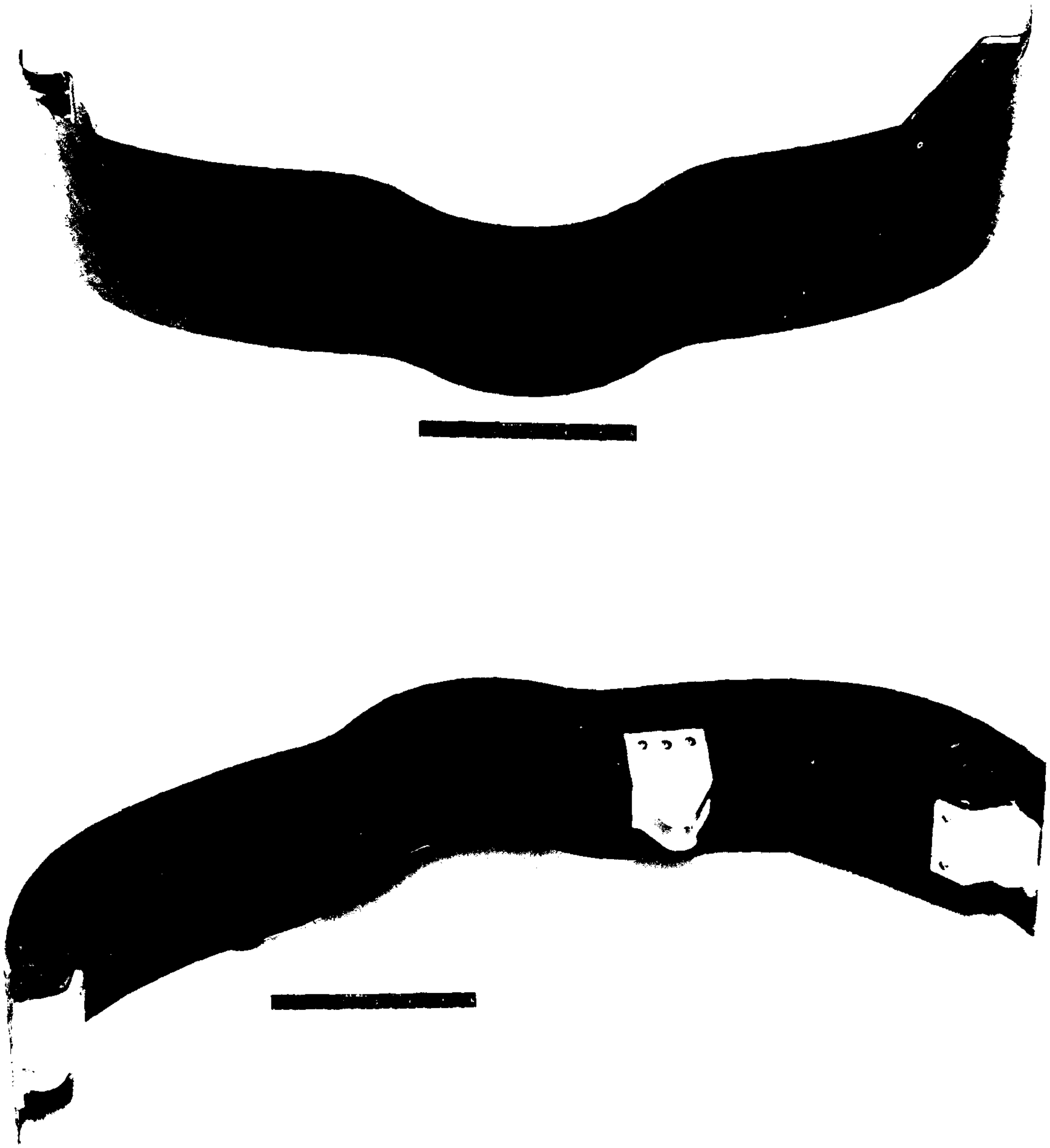


Figure 7-8. Completed Subelement Beam Section

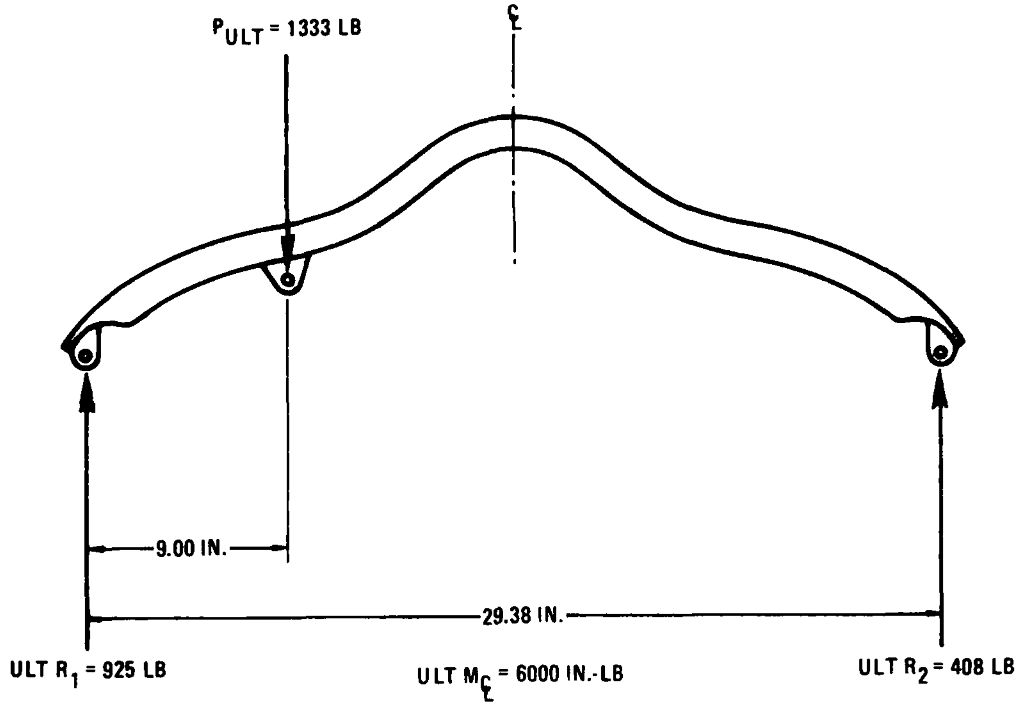


Figure 7-9. Beam Subcomponent Test Setup

SECTION 8

COMPONENT FABRICATION

Fabrication of the MLG door utilized a combination of processes. Each detail formed from graphite/thermoplastic established different methods of forming as being practical for use while at the same time demonstrating the requirements for flexibility when choosing the forming method for complex shapes.

8.1 MLG DOOR SKIN FORMING

Initial forming of the full-scale MLG door skin was accomplished using consolidated material and a silicone rubber vacuum bag. Heat (525F) was supplied by placing the die in an air oven. Results of the forming indicated that insufficient pressure was applied and wrinkles occurred from the silicone rubber bag. Figure 8-1 shows the results of the skin formed in this manner.

To eliminate the forming problems encountered with insufficient pressure, the forming process was changed to an autoclave forming method using a hard overpress made from polyimide and cloth.

Unconsolidated material was placed over the ceramic tool and the overpress placed on top of the material. Unconsolidatedmaterial was used to eliminate wrinkling since match tooling was not used which flows the material into place. Next, the tool was bagged with Kapton film, and a vacuum was applied. The tool was then placed in an autoclave and raised to a temperature of 550F. When temperature was reached, the vacuum was vented and a pressure of 80 psig was applied. The part was then cooled to below 300F under pressure. Pressure was then released, and the part was removed from the autoclave. Figure 8-2 shows the formed MLG door skin.

8.2 MLG DOOR SKIN DOUBLER.

Forming of the MLG door skin doubler was accomplished in the same manner as the door skin with one exception; the material was consolidated prior to forming. Consolidation of the forming blank was accomplished in an autoclave at 600F and 150 psi. The material was laid up and placed on a 0.250-inch-thick steel plate. A vacuum bag was placed over the material, which was placed in the autoclave. Temperature was raised to 600F, and 150 psi pressure was then applied. After the pressure was applied, the blank was cooled to below 300F under pressure and then removed.

Forming of the consolidated blank was accomplished by locating the blank on the ceramic tool, placing the polyimide overpress on the blank, placing a Kapton vacuum bag over the ceramic tool, and then forming in the same manner as the MLG door skin. Figure 8-3 shows the formed MLG door skin doubler along with the formed door skin.

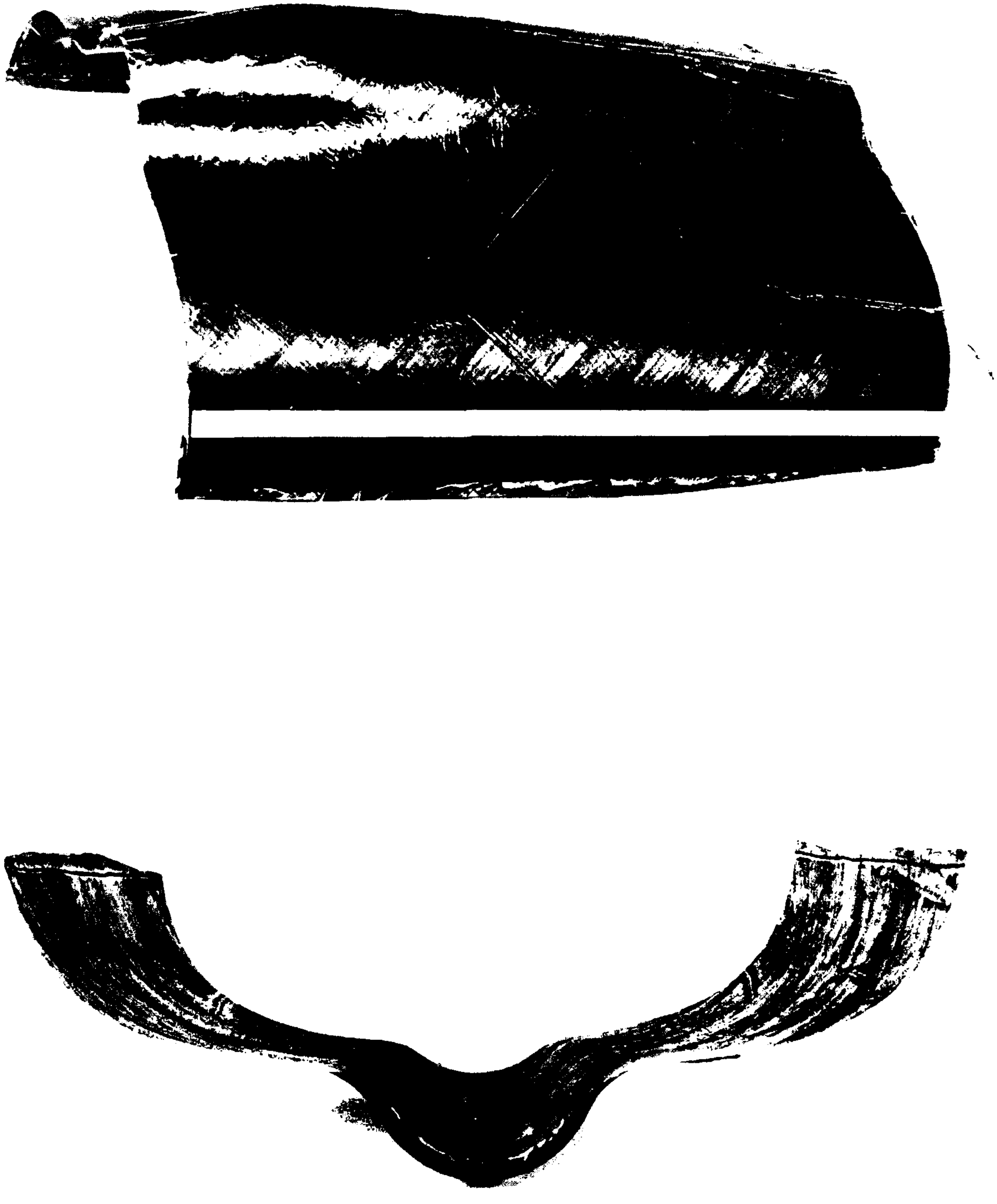


Figure 8-1. Skins Formed by Initial Process

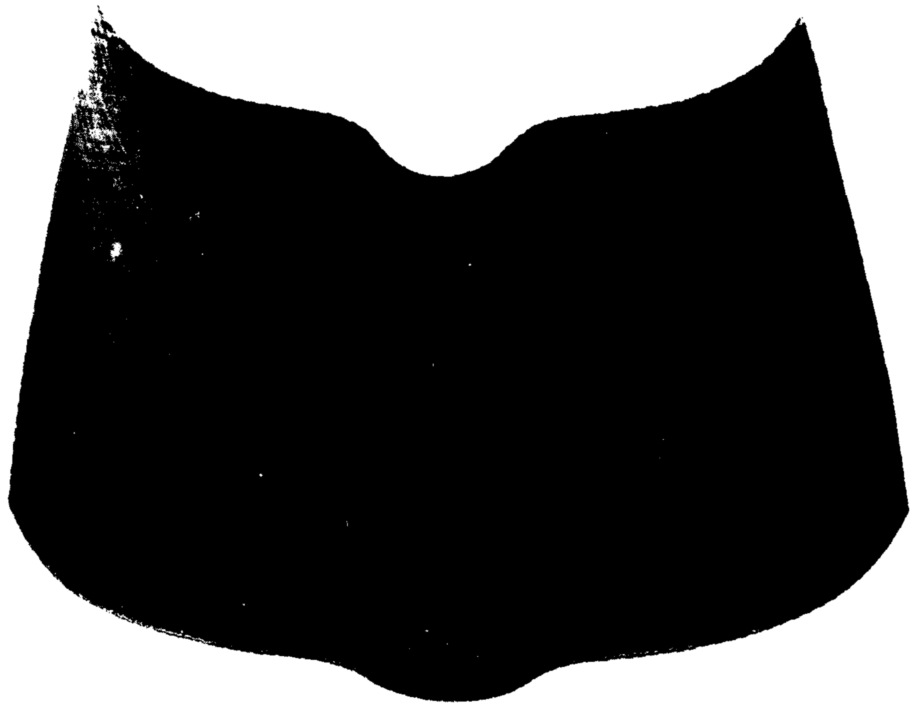


Figure 8-2. Formed MLG Door Skin

Figure 8-3. Formed MLG Door Skin Doubler and Door Skin

8.3 MLG DOOR LINER FORMING

Experience gained in forming of the MLG door skin indicated that forming of the liner would require a preforming operation prior to final forming in the autoclave. It was further determined that due to the complexity of the door liner the preforming operation would be accomplished using unconsolidated material.

Preforming of the MLG door liner was accomplished using a matched set of Kirksite dies. The dies were placed in an air oven and raised to 550F. Thermocouples were placed in both the upper punch and lower die to assure controlling the temperature of the tool and part.

After reaching temperature, the die set was removed from the oven and separated, the blank was placed in the tool, and the punch was slowly lowered to form the door liner. Figures 8-4, 8-5 and 8-6 show the forming of the door liner. After forming was completed the tool was allowed to cool to 300F, and then the punch was removed and the preformed part removed. The part was removed hot to be sure that it did not lock on the tool due to the differences in coefficient of expansion. Figure 8-7 shows the completed preformed door liner.

Final forming of the MLG door liner was accomplished using the ceramic tool with a silicone rubber overpress, with pressure applied with an autoclave. The preformed MLG door liner was placed on the ceramic tool and the silicone rubber overpress was placed on the part. The tool was then placed in an autoclave and the temperature raised to 550F. When temperature was reached the vacuum pressure was vented to atmosphere, and 80 psi pressure was applied with the autoclave. The part was then cooled to below 300F under pressure before removal from the autoclave. The formed MLG door liner is shown in Figure 8-8.

8.4 MLG DOOR LINER DOUBLER FORMING

Forming of the MLG door liner doubler was accomplished in the same manner as the MLG door liner. The liner was first preformed in the Kirksite tool and then final formed in an autoclave with an overpress and 80 psi pressure. However, during final forming of the liner doubler a primary bond to the door liner was also accomplished. Forming and bonding was performed by placing the preformed doubler on top of the liner, which was left on the ceramic tool. The overpress was placed over the liner doubler and liner, vacuum bag placed over the tool, and then the part was formed and primary bonded to the liner in a single operation.

8.5 BULKHEAD FORMING

Forming of the bulkheads was accomplished using a bladder forming system. Material was located on top of the form block, and a piece of silicone rubber was then clamped over the part using the clampdown ring.

Figure 8-4. Separating the Kirksite Die Set for Forming the MLG Door Liner

Figure 8-5. Forming of MLG Door Liner

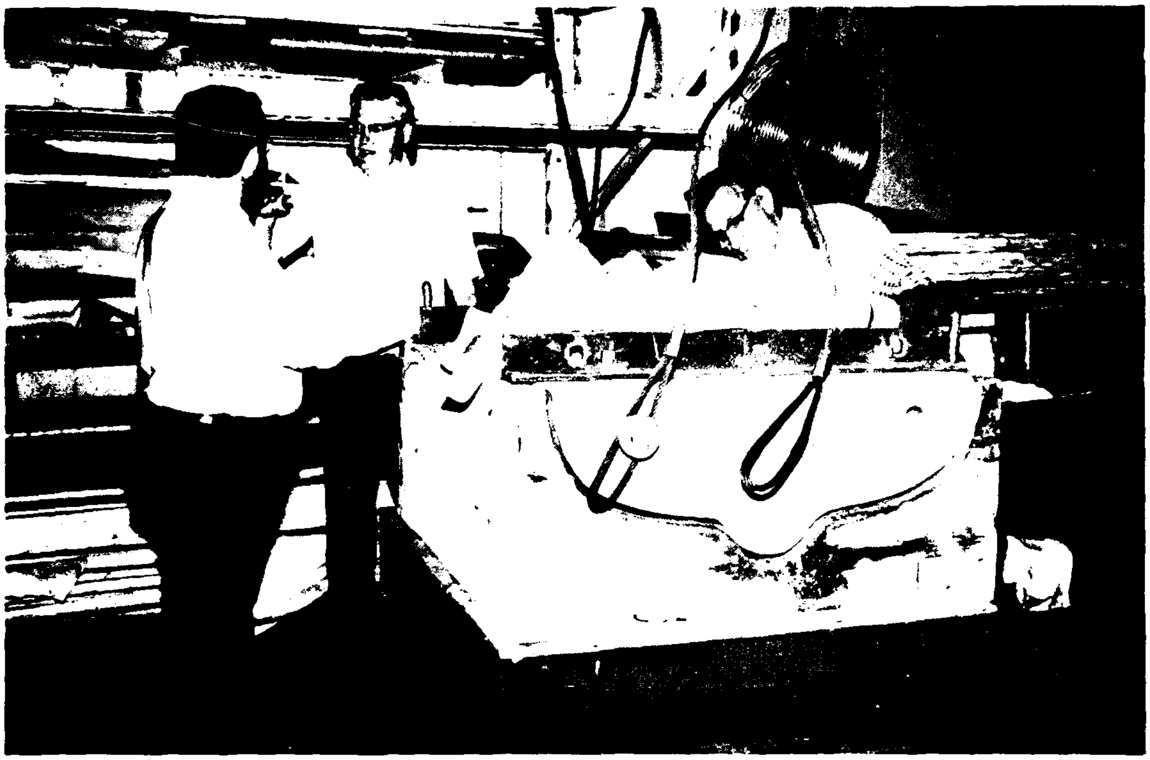


Figure 8-6. Form Die in Closed Position for MLG Door Liner

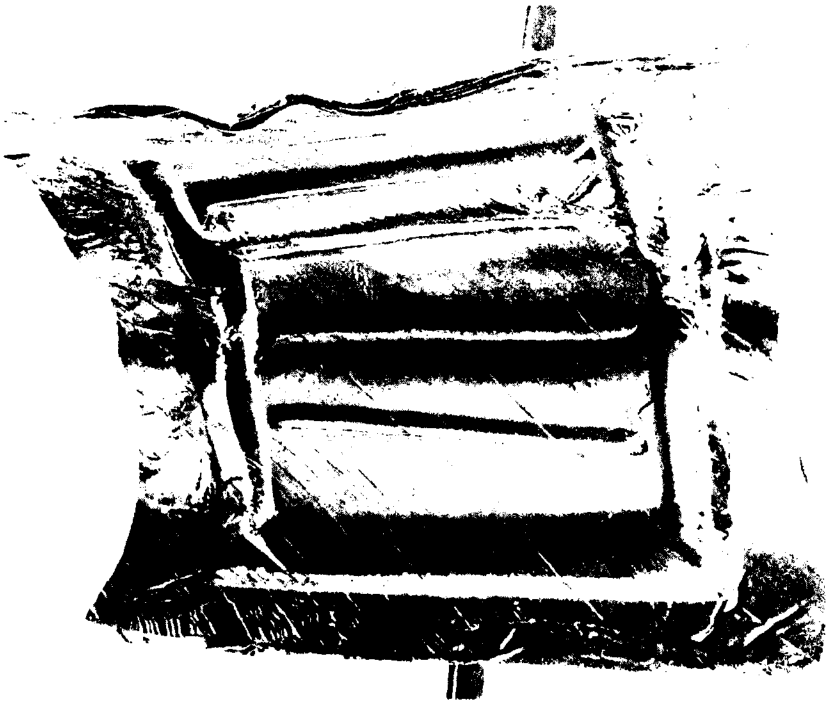


Figure 8-7. Preformed MLG Door Liner

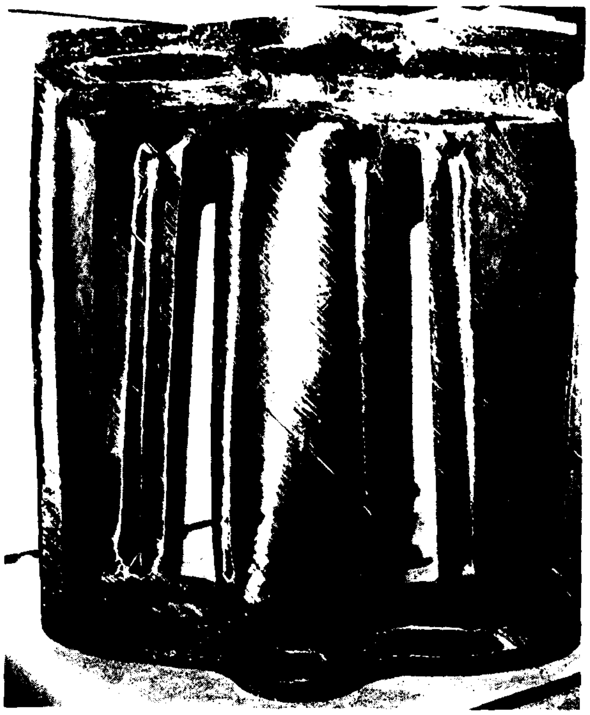


Figure 8-8. Formed MLG Door Liner

The tool was placed in the autoclave, raised to 550F, and then 80 psi pressure was applied to form the part. All four bulkheads were formed in this manner with full consolidation and meeting dimensional requirements.

8.6 DOOR LATCH AND HINGE FABRICATION

The MLG door latch and four hinges were machined from 2024-T851 aluminum using conventional machining methods. Figure 8-9 shows the completed machined parts.

8.7 MLG DOOR ASSEMBLY

Final assembly of the MLG door utilized adhesive bonding for the skin doubler to skin, bulkheads to skin and skin liner, and skin liner to skin. The skin liner doubler was primary bonded to the liner during forming. The door latch and hinges were attached using standard fasteners and two rivets were also used between each bulkhead and the door skin. Figure 8-10 shows the MLG door detail parts prior to final assembly.

The first assembly operation was to adhesive bond the bulkheads to the door liner and 0.010-inch thick backup plates for the door latch. The adhesive used was Hysol AE9309. Cleaning prior to adhesive bonding consisted of a quick wipe with methylene chloride. Figure 8-11 shows the bulkheads and aluminum plates bonded in place. After a 72-hour room-temperature cure of the adhesive, the door skin was adhesively bonded to the door liner subassembly. Figure 8-12 shows the final assembled door. Pressure

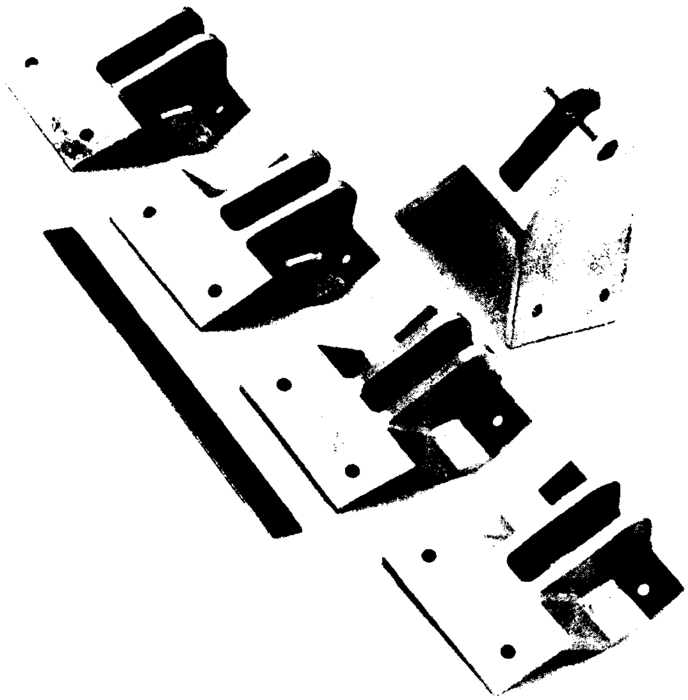


Figure 8-9. Machined MLG Door Latch and Hinges

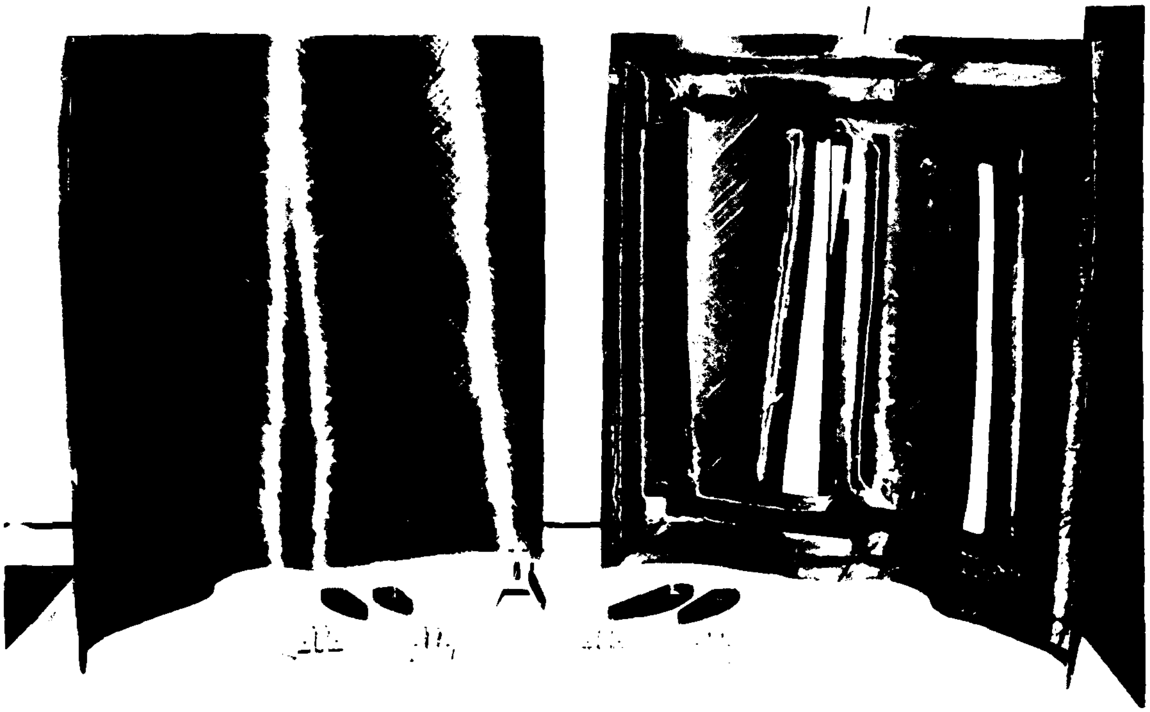


Figure 8-10. MLG Door Detail Parts

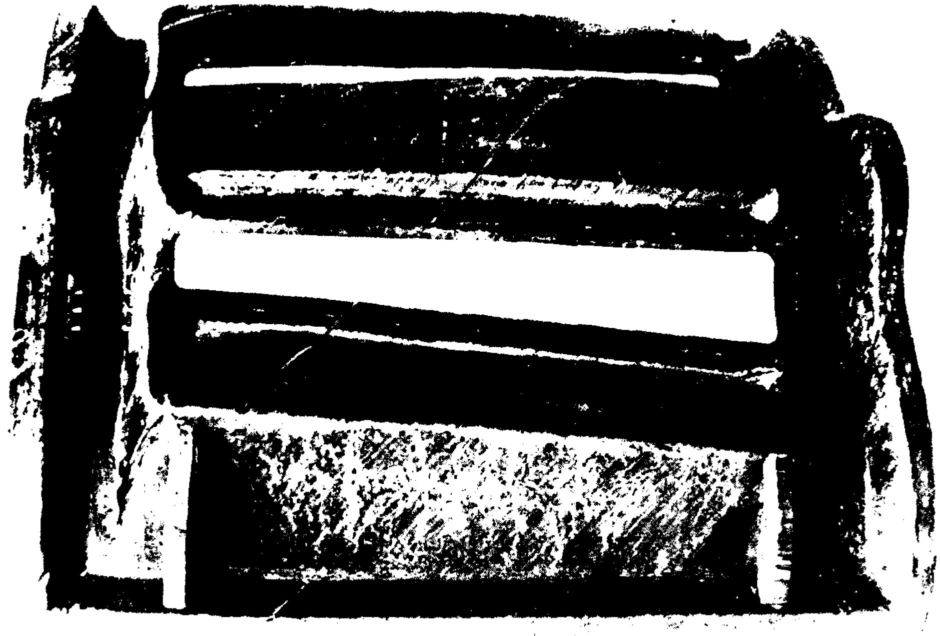


Figure 8-11. Bulkheads and Aluminum Plates Bonded in Place

Figure 8-12. Final Door Assembly

during forming was accomplished by bagging the assembly and applying vacuum pressure. After an additional 72-hour cure the door hinges and latch were assembled and the bulkheads riveted to the door skin. Final trimming of the door was accomplished using a bandsaw followed by filing to the trim lines on the part.

CONCLUSION

The major factor affecting the fabrication of the MLG Door was the selection of tooling material and the concept for forming. This program has pointed out that the use of matched tools is a requirement for forming components with a significant amount of compound contour. In addition, the tools should be heated and cooled to reduce manufacturing time for forming. Electro form nickel matched tools with heating and cooling attached to the back surface would be a prime candidate for production application.

SECTION 9

ECONOMIC ANALYSIS

The cost comparison was made between an all-metal door and a door fabricated from graphite/thermoplastic. The following ground rules and data were used by Convair Division Estimating.

1. Labor costs in constant 1975 dollars.
2. Show recurring and non-recurring costs separately.
3. All design and development tests have been completed.
4. Do not include profit.
5. Go-ahead January 1, 1976; period of performance 42 months.
6. Production rate:

1 per month for 6 months	6 ships
2 per month for 6 months	12 ships
4 per month for 6 months	24 ships
9 per month until completed	216 ships = 258 ships total.

7. Use 83 percent learning curve for composite and 76 percent curve for metal door.

9.1 METAL DOOR

9.1.1 DESCRIPTION. The door consists of a skin, a beaded and ribbed liner, four formed bulkheads, four metal fittings, and two doublers. The door has a compound contour and is 32 inches long, 30 inches wide, and 12 inches deep. The skin and liner are weld-bonded together. The bulkheads are bonded to the skin and liner, and the metal fittings are attached with mechanical fasteners.

9.1.2 GROUND RULES.

MAKE OR BUY POLICY. All items will be planned for in-house fabrication.

MANUFACTURING FACILITIES. All manufacturing facilities are available.

MANUFACTURING SEQUENCE

Detail Fabrication

1. Skin will be drop hammer formed with a single stage die.

2. Liner will be drop hammer formed requiring three stage dies.

3. Internal doubler will be drop hammer formed - single stage.

4. External doubler will be stretch formed.

5. Bulkheads (hinge and latch supports) will be hydropress formed.

6. Hinge, latch, and actuator fittings to be machined on Milwaukee-matic.

Assembly Sequence: Assemble the skin, liner, bulkheads, and doublers - rivet and weld bond.

Trim Perimeter: Assemble hinges, latches, and actuator fittings to weld bond assembly.

TOOL LIST METAL DOOR

Skin, 72C0476-7

1. Drop Hammer Die - Form complete - 1 stage
2. Trim Shell

Doubler (External), 72C0476-9

1. Stretch Form
2. Trim Shell

Liner, 72C0441-7

1. Drop Hammer Die
2. Trim Shell

Doubler (Internal) 72C0441-9

1. Drop Hammer Die (1 stage)
2. Trim Shell (Net)

Hinge Supports, 72C0482-7-9-11-13

1. Track Template (4)
2. Holding Fixture (4)
3. Tool Template (4)

Hinge, Latch and Actuator Fittings, 76C0477, 72C0478, 72C0479, 72C0480 and 72C0481

1. Production Tape (5)
2. Holding Fixture (2) (A/U all fittings)

Weld Bonded Assembly: Spotweld Fixture - Assemble skin, liner, supports, and doublers - rivet and weld bond.

Assembly: Assembly Fixture - Trim to net size and locate hinges, latches and actuator fittings.

9.1.3 COST OF METAL DOOR

1. Nonrecurring tooling - $70,600

2. Recurring tooling - $12,900

3. Material - $11,300

4. Factory - $128,377

5. Quality control - $14,500

6. Recurring engineering - $1,284

7. Average unit cost - $926

9.2 COMPOSITE DOOR

9.2.1 DESCRIPTION. The door consists of a skin, a stiffened liner, four formed bulkheads, five metal fittings, and two doublers. The door has a compound contour and is 32 inches long, 30 inches wide, and 12 inches deep. All of the composite parts are bonded together, and the metal fittings are attached with mechanical fasteners.

9.2.2 GROUND RULES.

MAKE OR BUY POLICY. All items will be planned for Convair to make with the exception of the graphite/thermoplastic (G/TP) tape and the ceramic tools required to obtain the compound contoured parts.

MANUFACTURING FACILITIES

1. All manufacturing facilities are available.

MANUFACTURING SEQUENCE

Material Receiving: Receiving inspection of the raw, six-inch, G/TP tape will be accomplished prior to any fabrication activities.

Fabrication - G/TP Module

1. Prepare flat steel plate to accept raw material.

2. Lay up six-inch tape to blueprint orientation. Use tape laying machine.

3. Press cure at 500F, 100 psi pressure for 10 minutes to consolidate module.

Fabrication - Skin (With Doubler)

1. Cut doubler pattern from G/TP module.

2. Place doubler in recess area of the male half of the production mold.

3. Place the rough pretrimmed skin G/TP pattern over the male half of production mold.

4. Drape glass fabric shroud around the production mold.

5. Apply 550 to 580°F heat to soften G/TP module.

6. Slowly raise base of mold to the upper half of mold until 10,000-pound load is achieved on the three force gages.

7. Cool mold to 250F.

8. Lower base of mold and remove part.

Fabrication - Liner Doubler

1. Cut doubler pattern from G/TP module.

2. Place doubler on lower half of production mold.

3. Repeat fabrication - skin (with doubler) operations 4 through 8.

4. Trim doubler net.

Fabrication - Liner

1. Place pretrimmed flat pattern G/TP module over lower half of mold.

2. Perform fabrication - skin (with doubler) operations 4 through 7 using starter die.

3. Perform fabrication - skin (with doubler) through 8 using finish die.

4. Trim liner cutout areas net.

Assembly - Liner and Doubler

1. Place liner in female mold half.

2. Locate doubler on liner.

3. Place vacuum bag over mold and pull vacuum.

4. Apply 550 to 580F to bond doubler to liner.

5. Cool mold to 250F.

6. Remove assembly.

Fabrication - Ribs

1. Place pretrimmed material over preheated mold.

2. Drape glass fabric shroud around mold.

3. Apply 550 to 580F heat to soften G/TP module.

4. Slowly close press to apply 50 psi to part.

5. Cool mold to 250F.

6. Open press and remove part.

7. Final trim part.

Assembly - Liner Assembly and Ribs

1. Place liner assembly in bond tool.

2. Pre-fit ribs four to liner assembly.

   a. Locate the four ribs contoured flanges to liner assembly.

3. Prepare bonding surfaces.

4. Apply adhesive to both surfaces.

5. Oven cure at 180F for 30 minutes.

Assembly - Skin and Liner Assembly

1. Place liner assembly in bond tool.

2. Prefit skin to liner assembly.

3. Prepare bonding surfaces.

4. Apply adhesive to both surfaces.

5. Place skin over liner assembly.

6. Apply vacuum bag.

7. Apply vacuum.

8. Remove assembly.

10. Trim assembly net.

Assembly - Door

1. Place skin assembly in assembly fixture.

2. Prefit two hinges, two latches, and two actuator fittings to assembly and to fixture.

3. Prepare bonding surfaces.

4. Apply adhesive.

5. Cure at room temperature.

6. Install fasteners.

7. Remove from fixture.

TOOL LIST

Skin/Doubler

1.	Marking Template	Trim G/TP module of skin.
2.	Production Mold	Matched mold electroformed nickel die of skin contour.
3.	Marking Template	Trim G/TP module of doubler.

Liner/Doubler

1.	Marking Template	Trim G/TP module of liner.
2.	Production Mold	Matched mold ceramic die of liner.
3.	Trim Shell	Trim liner cutout areas.
4.	Marking Template	Trim G/TP module of doubler.
5.	Trim Shell	Trim doubler net after form.

Ribs

1.	Production Mold (4)	Matched metal dies for flanged ribs (4) locations.
2.	Drill Plate (4)	Oversize flat pattern of ribs with tooling holes.
3.	Tool Template (4)	Mold pattern.
4.	Router Form (4)	Route ribs net.

Assembly

1.	Bond Tool	Position and bond ribs to liner assembly.
2.	Bond Tool	Position and bond skin to liner assembly.
3.	Trim Shell	Trim assembly perimeter net.
4.	Assembly Fixture	Locate and fasten hinges, fittings and actuator.

9.2.3 COST OF GRAPHITE/THERMOPLASTIC DOOR

1.	Nonrecurring tooling	$ 28,488
2.	Recurring tooling	8,100
3.	Material	131,580
4.	Factory	89,627
5.	Quality control	14,340
6.	Recurring engineering	1,900
7.	Average unit cost	1,058

9.3 CONCLUSIONS

In this study a composite door was designed and costed. For comparison purposes it was assumed that a metal door would be the same design (number of parts and material thicknesses). The only difference in the design of the doors was that the composite door was a pure bond assembly and the metal door was weld-bonded.

In both doors, the skin, liner, and bulkheads were formed on dies and both had identical fittings.

To fabricate a composite door that would be cost competitive with a sheet metal door the design of the composite door must reduce the number of parts to be fabricated and assembled and reduce the thickness of the material required.

A less time consuming method of heat tacking the tape together would help reduce the time to layup the material modules.

SECTION 10

COMPONENT TESTING

The graphite/thermoplastic main landing gear door was tested under static load at the Naval Air Development Center, Warminster, Pennsylvania, during March 1977. Both the door-open and door-closed conditions were run. In the latter configuration, the structure withstood the maximum applied load (150 percent of design limit load) without any apparent damage. Failure occurred at 144 percent of design limit load in the door-open test.

10.1 LOADING CONDITIONS

In order to obtain satisfactory simulation of the door-open and door-closed service conditions, two different load distributions were required. This was achieved without repositioning the door in the test fixture. It was only necessary to alter the load intensities among the pressure pads and to incorporate or remove the restraining latches and pins, as appropriate.

10.1.1 DOOR-OPEN LOADING CONDITION. The door-open test load distribution is illustrated in Figure 10-1. This constitutes an idealization of the Model 200 predicted service loading. The actual center of pressure is duplicated and the magnitudes were adjusted to preserve the total limit load of 1,532 pounds. The loads were applied normal to the door contour. Local intensities at the discrete pressure pads did not exceed 50 psi. With the door in the open configuration, the applied loads were reacted at the two hinge fittings and the single actuator strut which attaches to the forward beam. These locations are shown in Figure 10-2.

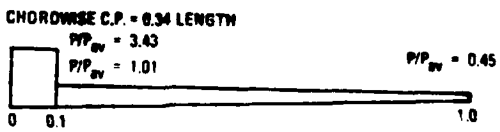


Figure 10-1. Door-Open Chordwise Load Distribution

10.1.2 DOOR-CLOSED LOADING CONDITION. The applied test loads for the door-closed condition were equivalent to a uniform limit pressure of 240 psf acting normal to a theoretical flat plate of the same projected area as the door. This corresponded to a design limit load of 1,704 lbs. acting approximately at the mid-point of the door chord. The test loads were applied normal to the door contour and were suitably adjusted to permit vectorial resolution into vertical components having this summation. With the door in the closed configuration. the applied loads were reacted by the two hinges and the two latches. These locations are shown in Figure 10-2.

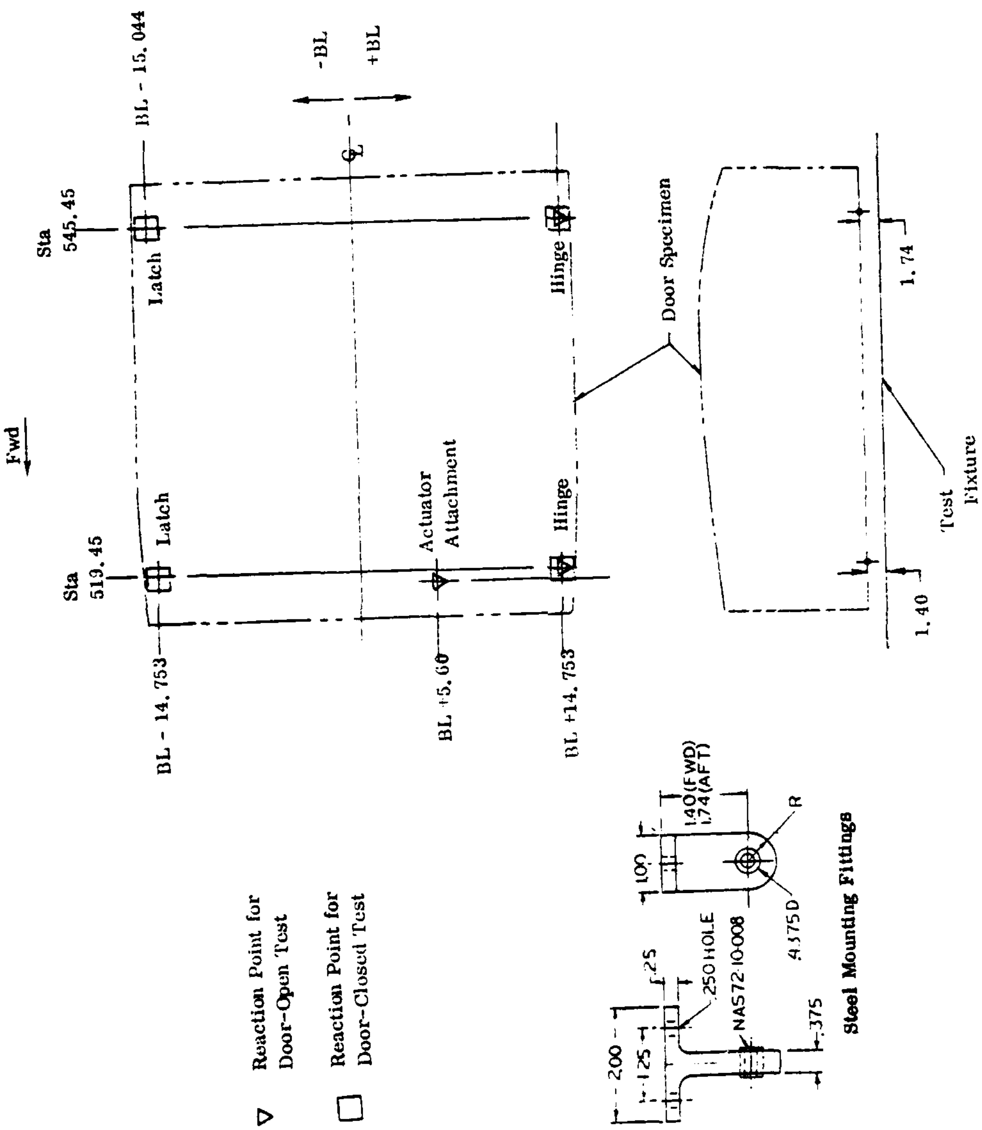


Figure 10-2. Test Setup

10.2 TEST SETUP

A photograph of the test arrangement is given in Figure 10-3. The setup is depicted schematically in Figure 10-2. This figure indicates the locations of the hinges, latches, actuator attachment point, and orientation in the test fixture. It was originally intended that the door-open configuration would be attained by simply removing the restraining pins from the latches. However, the data obtained from the first door-open test showed that considerable friction was present in the system. This was traced to the latches which were binding up as a result of the door distortion under load. This difficulty was surmounted by completely removing the latch fittings for the door-open testing.

10.3 INSTRUMENTATION

To monitor and evaluate the structural behavior of the door, nine linear motion transducers were employed to measure displacements while local strains were recorded by means of an array of forty-two strain gages. The transducers were positioned as indicated in Figure 10-4. Figure 10-5 gives the strain gage locations.

10.4 TEST RESULTS

The graphite/thermoplastic main landing gear door was subjected to the following sequence of tests at the Naval Air Development Center, Warminster, Pennsylvania:

a. Test No. 1; Door Open (3/16/77) - Loaded to 100 percent of design limit load with latch fittings in place. No failure. Data indicated presence of considerable friction due to latch fitting interference.

b. Test No. 2; Door Open (3/16/77) - A repeat of the preceding test but with latch fittings removed. Loaded to 100 percent of design limit load. No failure. Data indicated that the friction problem was eliminated.

c. Test No. 3; Door Closed (3/17/77) - Loaded to 100 percent of design limit load. No failure.

d. Test No. 4; Door Closed (3/17/77) - Loaded to 150 percent of design limit load. No failure.

e. Test No. 5; Door Open (3/18/77) - Loaded to failure which occurred at 144 percent of design limit load in the form of delamination of the inner cap and upright webs of the forward beam at the door centerline. This is shown in Figures 10-6 and 10-7. As shown in Figure 10-8, some delamination also appeared in the region of strain gage 0 and was quite likely a secondary failure.

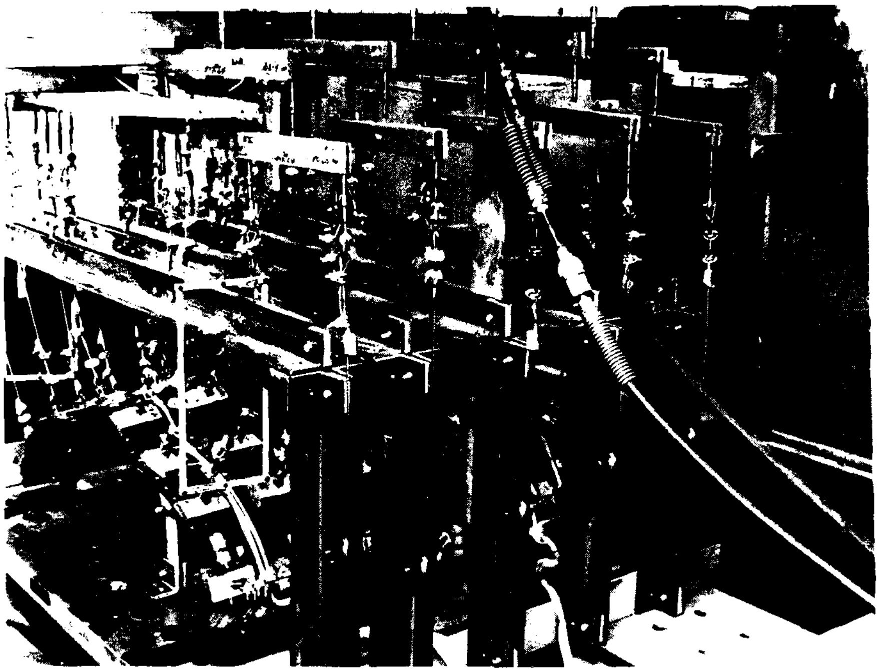


Figure 10-3. Test Arrangement

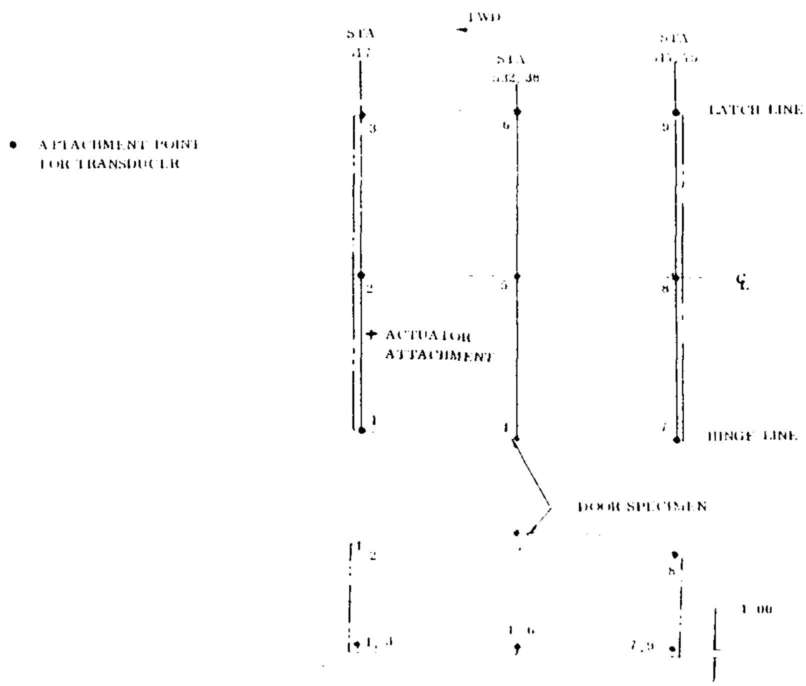
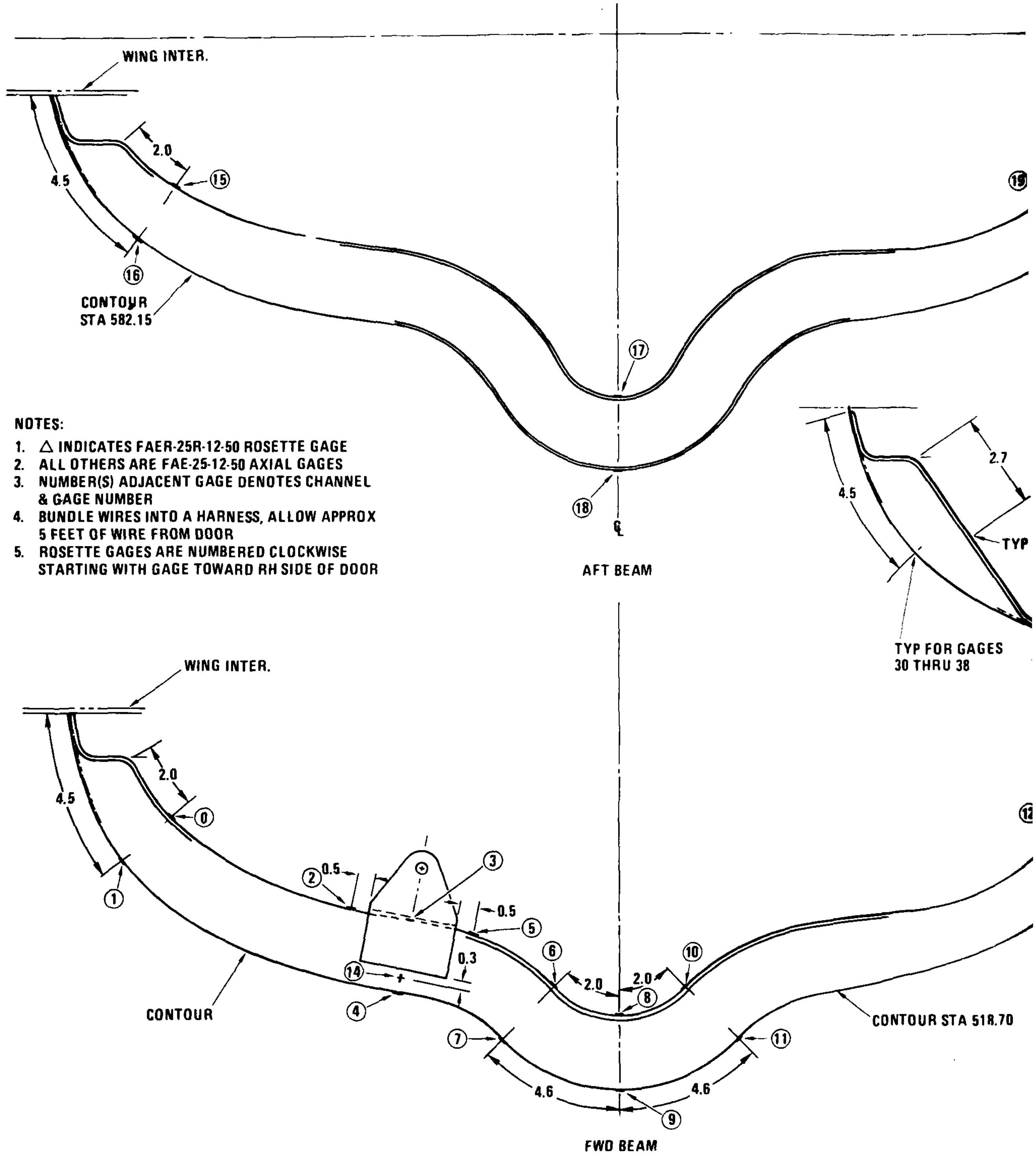


Figure 10-4. Displacement Transducer Locations



NOTES:

1. △ INDICATES FAER-25R-12-50 ROSETTE GAGE
2. ALL OTHERS ARE FAE-25-12-50 AXIAL GAGES
3. NUMBER(S) ADJACENT GAGE DENOTES CHANNEL & GAGE NUMBER
4. BUNDLE WIRES INTO A HARNESS, ALLOW APPROX 5 FEET OF WIRE FROM DOOR
5. ROSETTE GAGES ARE NUMBERED CLOCKWISE STARTING WITH GAGE TOWARD RH SIDE OF DOOR

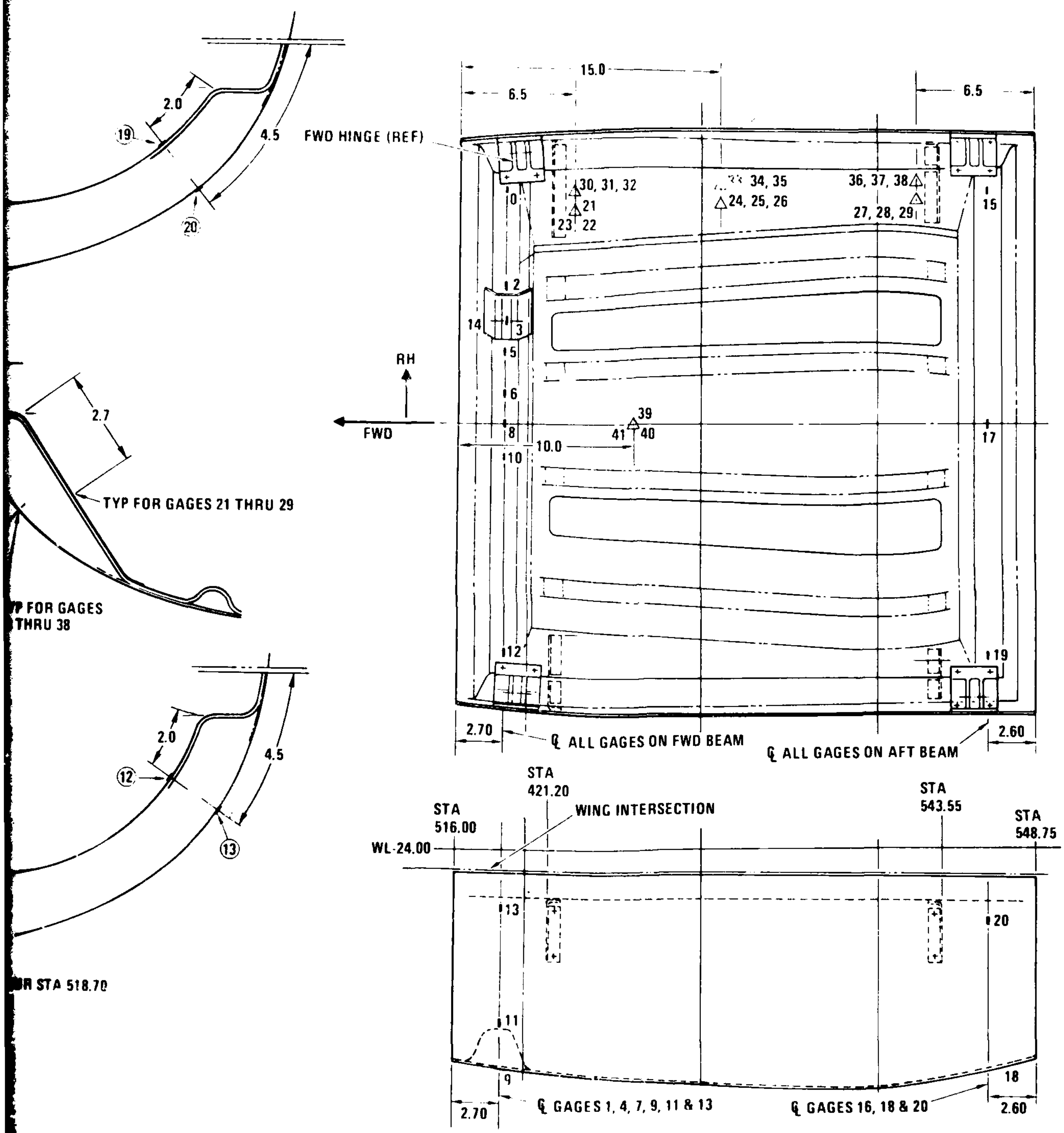


Figure 10-5. Strain Gage Locations

AD-A088 103 GENERAL DYNAMICS SAN DIEGO CA CONVAIR DIV F/G 11/4
DEVELOPMENT OF A LOW COST GRAPHITE REINFORCED COMPOSITE SECONDA--ETC(U)
OCT 75 R C GOAD, W F WENNHOLD N62269-74-C-0369
UNCLASSIFIED CASD/NSC-74-005 NADC-77231-30 NL

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Figure 10-6. Failure of Forward Beam Inner Web at Centerline of Door

Figure 10-7. Failure of Forward Beam Outer Web at Centerline of Door

Figure 10-8. Delamination of Forward Beam Adjacent to Hinge Location

10.4.1 DEFLECTION DATA. In the door-closed configuration, the measured deflections were all well below 0.10 inches, the maximum design allowable for that condition. However, major deflections were experienced in the door-open tests. The corresponding displacement surface, as obtained from the transducer data, is presented in Figure 10-9. This is shown for the last load increment prior to ultimate failure of the door in Test No. 5. The maximum displacement was 2.464 inches. As expected, this occurred at the corner furthest from the actuator attachment point. A plot of load vs. deflection at this location is given in Figure 10-10. This curve is essentially linear up to 125% limit load (approximately 87% of failing load).

10.4.2 STRAIN GAGE DATA. As expected, in the closed-door tests all the strains were very small. By far the largest value was only .0031 in./in. and this was obtained from strain gage 17. Since this gage clearly malfunctioned in subsequent open-door testing, even the .0031 indication may well have been an excessive measure of the actual deformation.

To gain a feel for the physical significance of the strain gage output, the forward and aft beam data were converted to stresses. For this purpose, it was assumed that a uniaxial state of stress existed in these members. This was the only alternative open since all but one of the gages on these beams were of the single axial variety

oriented in the spanwise direction. Computation of stresses required a knowledge of the elastic modulii for the composite material laminates used in the door construction. In particular, the stacking sequences were as follows:

Liner $[\pm 45/90/\pm 45/90/0_2]_s$

Skin $[\pm 45]_{s2}$

The modulii and primary Poisson's ratio of an individual lamina were assumed to be as given below:

$$E_{11}^{t} = E_{11}^{c} = 15.0 \times 10^6$$

$$E_{22}^{t} = E_{22}^{c} = 1.5 \times 10^6$$

$$G_{12} = 0.86 \times 10^6$$

$$\mu_{12} = 0.27$$

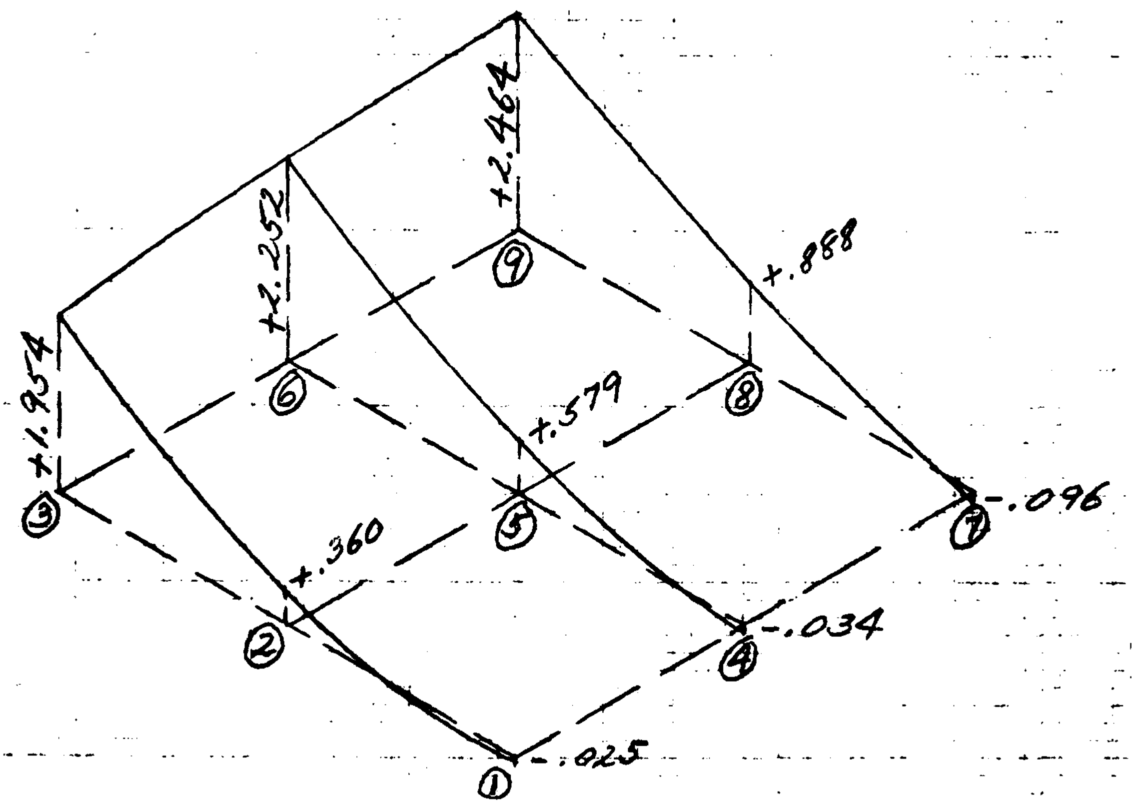


Figure 10-9. Deflection Surface for Door-Open Configuration at 140 percent of Design Limit Load

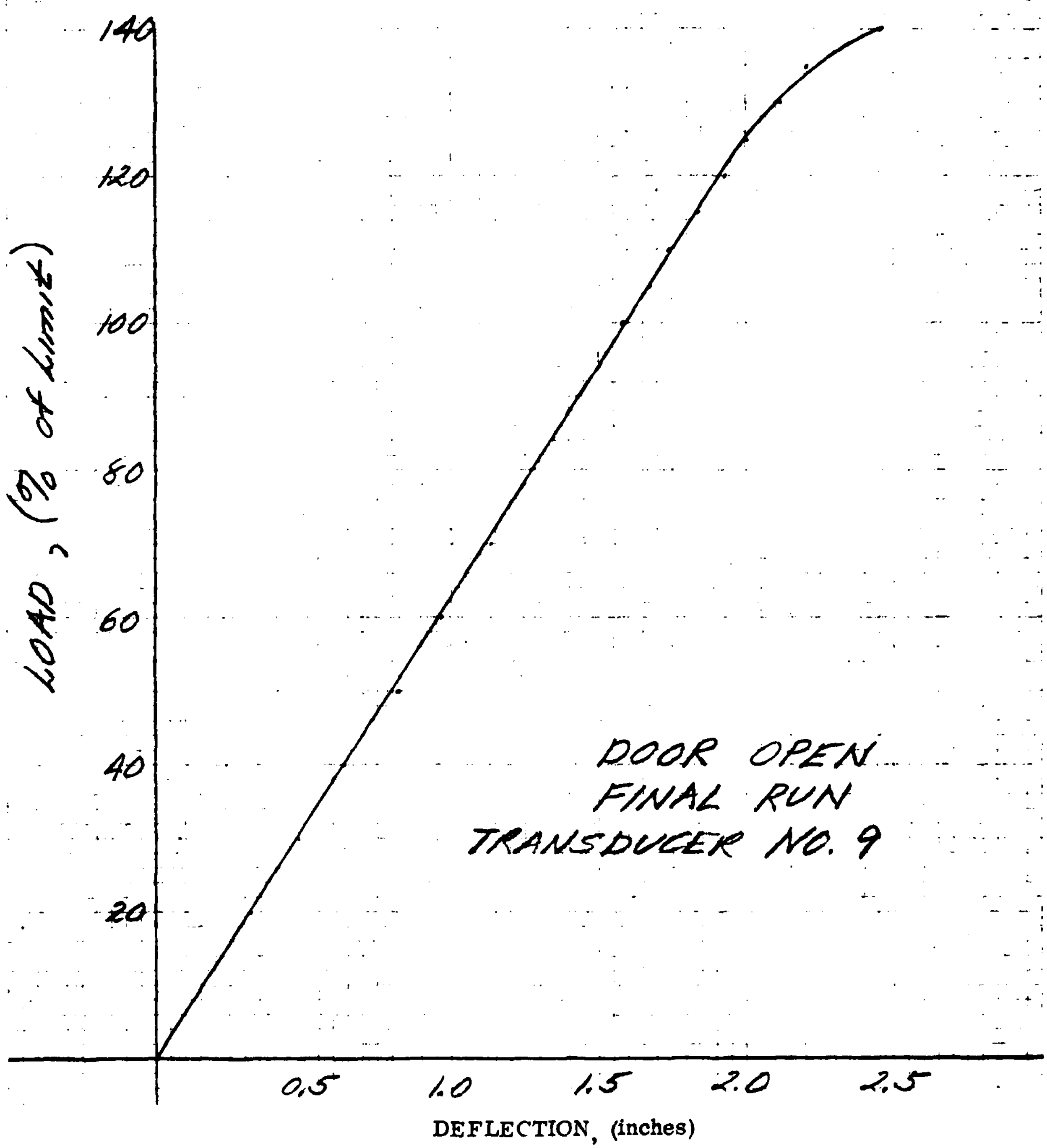


Figure 10-10. Maximum Deflection versus Load for Door-Open Configuration

By using these values in conjunction with Convair digital computer program SQ5, the following results were obtained for the laminates of interest:

LAMINATE	EX = EY	GXY	$\mu_{xy} = \mu_{yx}$
Liner	6.20×10^6	2.41×10^6	.289
Skin	2.87×10^6	3.95×10^6	.670
Liner & Skin	5.27×10^6	2.92×10^6	.395

These values were also used to convert the analytical stress predictions into strains.

Figure 10-11 presents plots of the measured spanwise strains in the forward and aft beams for the final door-open test during which failure occurred at 144 percent of design limit load. As expected, the values from gages 0 and 1 were very small since these gages were positioned in a region where the beam bending was predicted to be negligible. This is illustrated in Figure 10-11. The limit strains from gages 0 and 1 correspond to stresses of only -1,230 psi and -810 psi, respectively.

Strain gages 2 through 5 were positioned in the neighborhood of the actuator attachment on the forward beam. As indicated in Figure 10-11, considerable bending was expected in this region and the strain gages showed this to be the case. The inner cap of the beam was in tension and the strains measured there were in perfect agreement with those from the stress analysis. At limit load, strain gage number 3 gave a reading of +.00342 in/in while the analytical prediction was +.00343 in/in (+21,270 psi). On the other hand, the stress analysis projected that the skin-flange buildup would experience a limit strain of -.00289 in/in whereas gage 4 showed a skin measurement of only -.00119. This discrepancy can be partly attributed to positioning of the strain gage on the centerline of the beam roughly two inches away from either of the hat-section upright legs. Shear lag effects as well as some curved-beam influences carried over from nearby sharply contoured areas could contribute to a reduction in magnitude of the compressive strain at the gage location. More will be said on this phenomenon in the discussion which follows for gages surrounding the centerline of the door.

It was anticipated that gages 6 through 11 would all indicate a high degree of bending together with small net tensile forces acting parallel to the beam centerline. As shown in Table 10-1, the measurements fell far short of the predictions and would tend to indicate the presence of an unreasonably high net tension. It is thought that this is the result of the curved-beam phenomena described by Westrup and Silver in Reference 10-1. As noted there, induced radial loadings due to curvature can cause

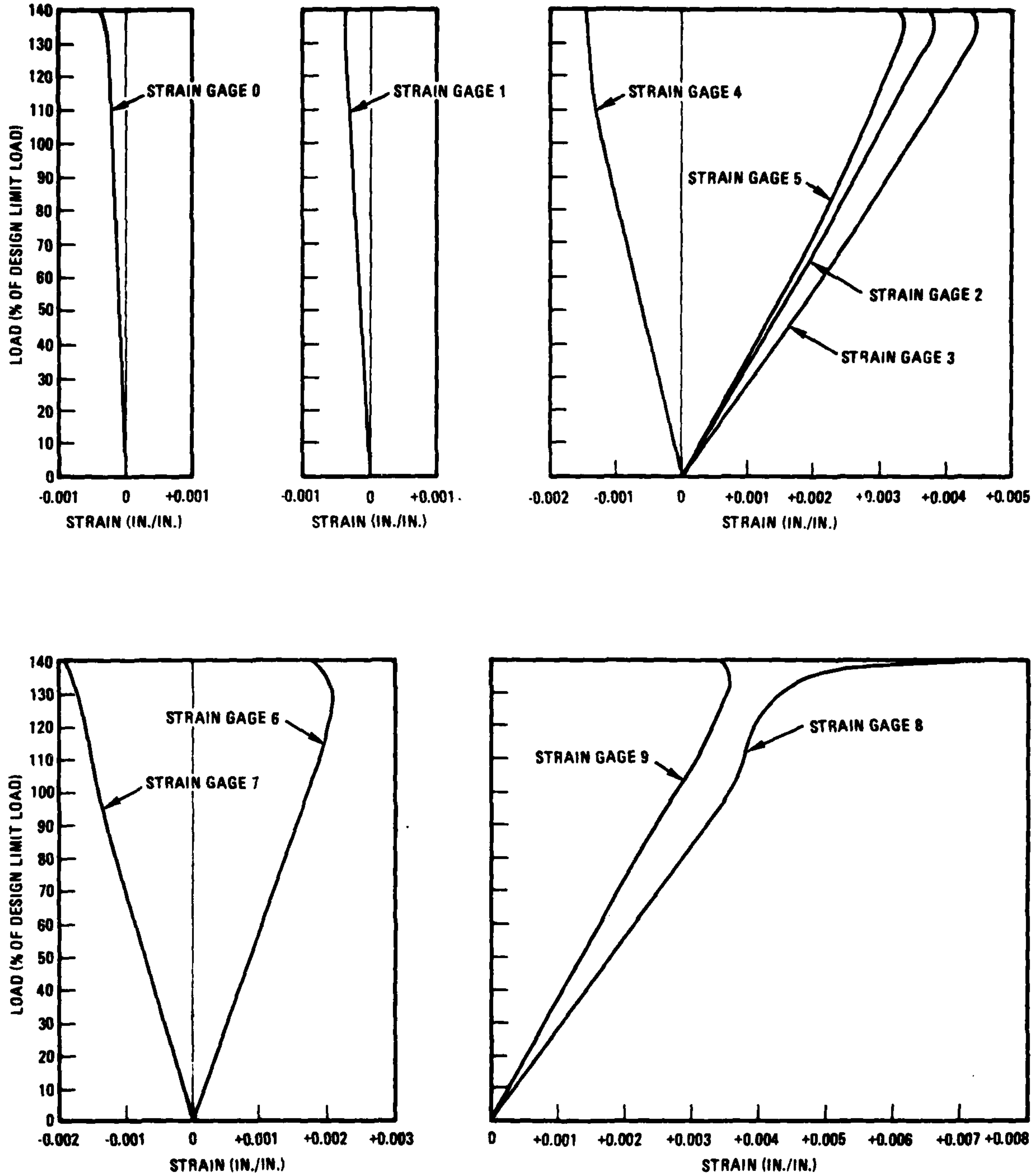


Figure 10-11. Strain Gage Data For Door-Open Test to Failure

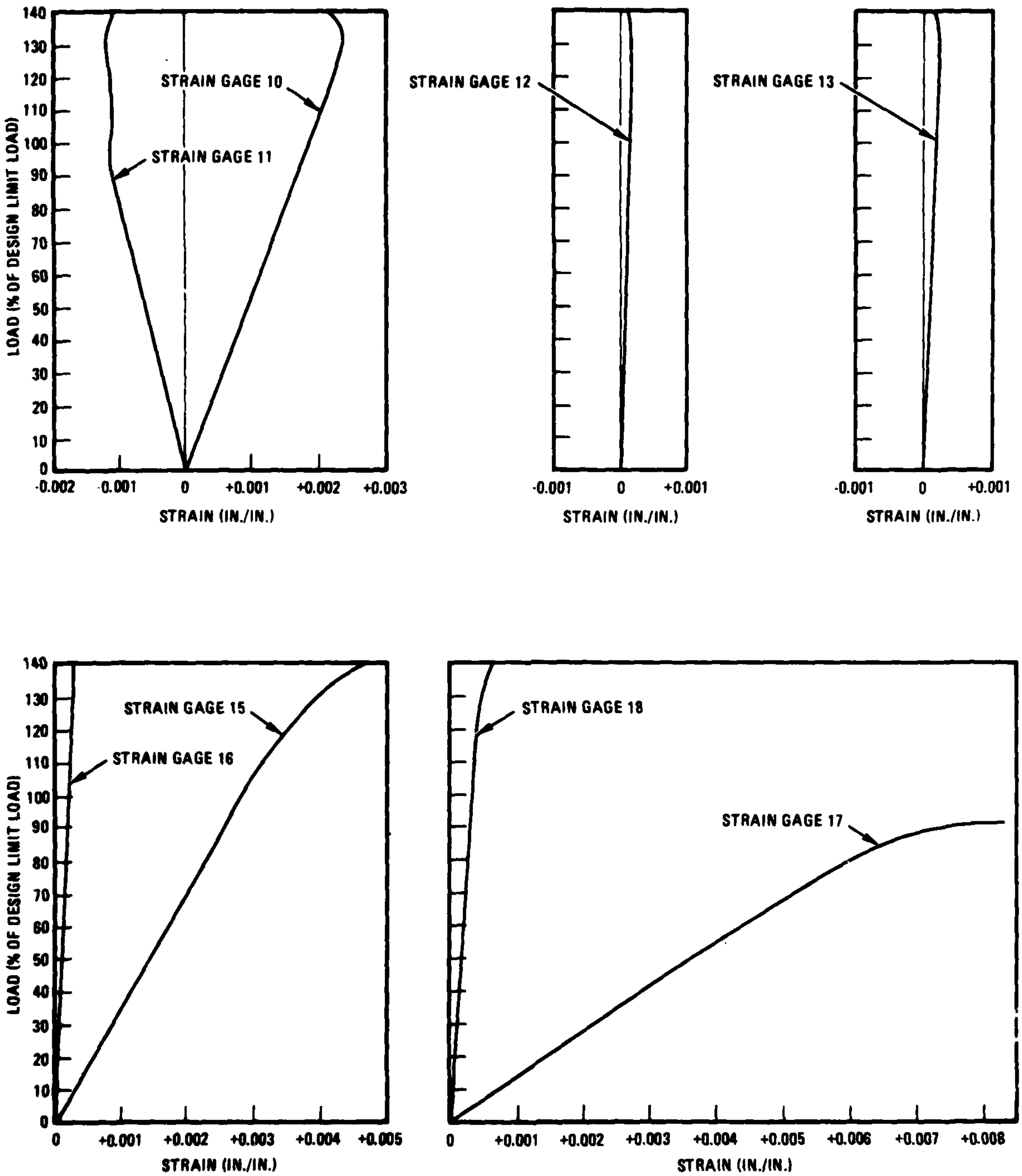


Figure 10-11. Strain Gage Data For Door-Open Test to Failure, Contd

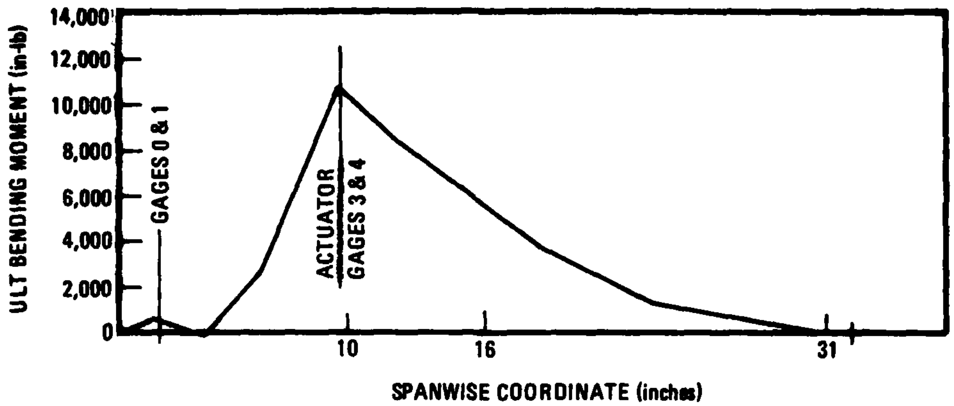


Figure 10-12. Predicted Bending Moment Diagram for Forward Beam with Door Open

Table 10-1. Comparison of Measurements vs. Predictions for Sharply Curved Region of Forward Beam

Strain Gage	Predicted Limit Stress (PSI)	Predicted Limit Strain (in/in)	Measured Limit Strain (in/in)
6	+36,830	+.00594	+.00171
7	-34,760	-.00660	-.00144
8	+32,660	+.00527	+.00358
9	-24,370	-.00462	+.00273
10	------	------	+.00184
11	------	------	-.00117

drastic changes in beam stress distributions from that predicted by elementary bending theory. This was recognized in the stress analysis through the introduction of appropriate efficiency factors that accounted for the loss of cap and flange effectivities because of extremely sharp curvature at the door centerline. The general characteristics of stress distributions in the cap and flange elements should be such that the stresses are highest at the upright webs and decay with distance from the web line. Computations were made using the Westrup and Silver equations for frame caps that can be represented as curved plates having both long edges simply supported. This condition was considered to be representative of the skin between the beam upright legs. For isotropic materials, the appropriate relationships are as follows:

$$\frac{\sigma}{\sigma_w} = (C_1 \sinh \beta x + C_2 \cosh \beta x) \sin \beta x + (C_3 \sinh \beta x + C_4 \cosh \beta x) \cos \beta x$$

where

$$\beta = [3(1-\nu^2) / t^2 R^2]^{1/4}$$

$$C_1 = 0$$

$$C_2 = \frac{(\cosh \beta b - \cos \beta b) \sin \beta b}{\sinh^2 \beta b + \sin^2 \beta b}$$

$$C_3 = -\frac{(\cosh \beta b - \cos \beta b) \sinh \beta b}{\sinh^2 \beta b + \sin^2 \beta b}$$

$$C_4 = 1$$

and

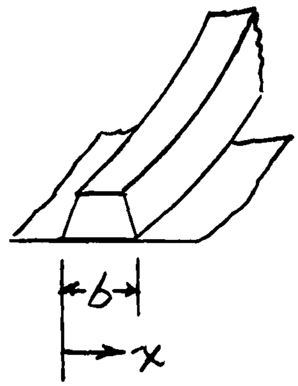
b = Plate width, in.
t = Plate thickness, in.
R = Radius, in.
x = Distance from simply supported edge, in.
ν = Poisson's ratio
σ = Stress, psi
σ_w = Stress at web location ($x = 0$ and $x = b$), psi

The only recognition made here of the fact that the skin was anisotropic was to use the appropriate laminate Poisson's ratio. No rederivations were performed to arrive at equivalent anisotropic formulations. It was felt that this would be unwarranted since the purpose of the immediate computations was only to explore a possible explanation for the general characteristics of the strain distributions observed in the test. The results obtained are shown in Table 10-2. The specified R and t values correspond to the skin values at the centerline of the door. The skin width b for both the forward and aft beams of the main landing gear door is approximately 3.75 inches. It can be seen from the table that, for widths of such magnitude, the stress mid-way between the upright webs ($x = b/2$) can be a very small fraction of the stress at the web locations. In addition, note that even sign reversals are possible. Since the beam strain gages were located at the cross-sectional positions furthest removed from the upright legs, it is therefore not surprising that the associated strain measurements would be smaller than the analytical predictions. This could likewise be a possible explanation of the unexpected sign from the output of gage 9.

Expectations were that gages 12 and 13 would yield negligible strain measurements in view of the bending moment diagram of Figure 10-12. This was indeed the case. The measured limit strain values were +.000138 and +.000214 in/in which correspond to stresses of +860 and +610 psi, respectively.

Table 10-2. Influence of Plate Width on Curved Beam Effects

R = 4.5 in. t = 0.040 in.	
b (in.)	$\left(\frac{\sigma}{\sigma_W}\right)_{x = \frac{b}{2}}$
1	+.137
2	-.121
3	-.021
4	+.006
5	+.002
6	0
7	0



Gages 15 and 16, which are located on the aft beam, conform with the anticipation that the bending moment for this beam would peak closer to the hinge line than would that for the forward beam. This relationship is illustrated by the superimposed display of both moment diagrams in Figure 10-13.

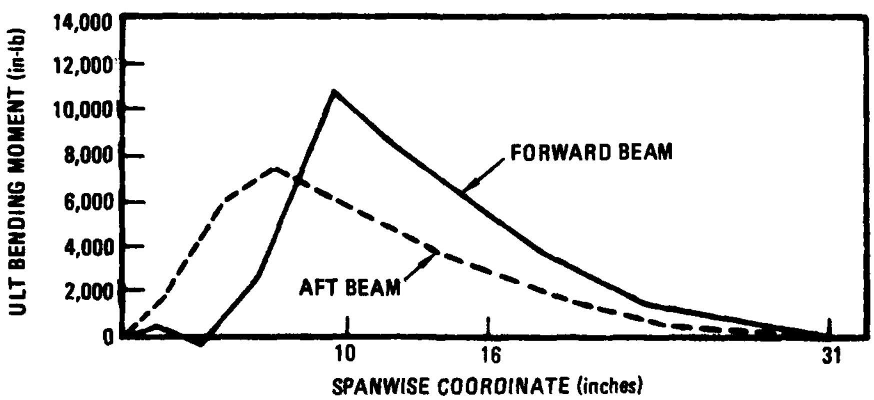


Figure 10-13. Comparison of Predicted Bending Moments in Forward and Aft Beams

From the plots of Figure 10-11, it is rather clear that strain gage 17 malfunctioned. At approximately 90 percent of design limit load, the strain appears to increase

without bound. Thereafter, the gage ceased to operate. Since this behavior is incompatible with the other plots of both strains and deflections, it is concluded that this reflected a faulty gage rather than a structural failure. The companion gage (No. 18) was well-behaved except for its indication of positive strain when the reverse was anticipated. This is analogous to the situation at mid-span of the forward beam and the associated discussion of curved-beam effects is equally applicable here.

As expected, the readings from strain gages 19 and 20 are very small. This is quite reasonable since the beam bending was predicted to be negligible at their location. The measured limit strains are only +.000220 and +.000034 in/in which correspond to stresses of +1,360 and +100 psi, respectively.

10.5 REFERENCES

10-1. Westrup, W. W. and Silver, P., "Some Effects of Curvature on Frames," Journal of the Aero/Space Sciences, September 1958.

SECTION 11

CONCLUSIONS AND RECOMMENDATIONS

Based upon the work performed on this program and presented in this report, the following conclusions and recommendations are made.

11.1 DESIGN, ANALYSIS, AND TEST

1. A large aircraft, secondary structural component was designed utilizing a graphite/thermoplastic material system. The selected component was the main landing gear door of the Convair Model 200 Navy V/STOL fighter-attack aircraft. The design was supported by theoretical analysis for both the door-closed and door-open conditions. In subsequent full-scale testing, the ultimate door-closed loading was successfully carried. When tested in the open configuration, the door withstood loading very close to the design ultimate values. Failure occurred at 96 percent of ultimate. For the one-article development program pursued here, this is considered to be essential verification of the design and increases the level of confidence in use of the graphite/thermoplastic material. In a larger scale development program, the material consolidation and fiber direction control would certainly be improved and result in a higher quality part than was produced under this contract.

2. Certain features of the selected door configuration make it difficult to perform a stress analysis by the routine application of linear finite-element computer programs. The sharp curvatures of both the forward and aft beam initial contours cause changes in the stress distributions from that predicted by elementary bending theory. This creates the necessity for accurate modeling of the beams as an assemblage of many membrane or plate elements as opposed to discrete beam elements. In addition, the large deflections of the door in the open condition make it questionable to employ a theoretical approach based entirely on the original undeformed geometry.

3. Five design concepts of a graphite/thermoplastic door were compared with a metal baseline door for weight savings and ease of manufacture. The two piece skin liner design selected for the demonstration article had a calculated weight savings of 29% and required the fewest tools for fabrication. More complex designs which would have had higher fabrication costs showed calculated weight savings up to 48.2 percent.

4. The metal baseline door and the graphite/thermoplastic design selected for the demonstration article were considered beyond the state-of-the-art for metal forming. The designs were considered formable with graphite/thermoplastic.

11.2 MATERIAL PROPERTY TESTING

1. Material properties were determined on unidirectional and pseudoisotropic cross-plied graphite/thermoplastic Type A-S/P1700. In general strengths were similar to Type A-S epoxy strength. Insufficient testing was conducted to determine all design allowables. Because of the similarity to A-S/epoxy the A-S/epoxy values were used for the design and only verification testing was conducted when required.

2. The use of N-methyl pyrolidone (NMP) as a solvent for prepregging should be avoided. Methylene chloride as a solvent produces material that displays higher compression and flexural strengths. Methylene chloride produced prepreg material has better filament to resin bond.

3. The P-1700 polysulfone material is attacked by a large number of industrial solvents including chemicals found in paint strippers. A more resistant thermoplastic resin is desirable as well as one that would have used temperatures up to 300F rather than the 270F to which polysulfone is limited.

11.3 MANUFACTURING DEVELOPMENTS

1. Complex shapes can be formed using the A-S/polysulfone material system.

2. Multiple stage forming is required for complex shapes when using vacuum bag or autoclave forming. The material is restrained by the bagging material and is not allowed to move freely.

3. Unconsolidated material is easier to form by the vacuum bag or autoclave forming technique in that the thinner plies of material can move independent of each other.

4. Overpresses are required for autoclave or vacuum forming. Glass-reinforced silicone rubber is a satisfactory material; however, glass polyimide appears to be superior.

5. If autoclave forming of complex shapes is performed, a preform is required.

6. The selection of tooling is a key factor in the forming of graphite-reinforced thermoplastics. Whenever possible matched form tooling should be used.

11.4 COMPONENT FABRICATION

1. Matched dies are required for forming to achieve high quality parts at the lowest cost.

2. Precision Kirksite dies can be used for preforming thermoplastic parts and possibly for final forming for low production runs.

3. Cast ceramic tooling does not possess sufficient strength and durability for production usage.

4. The type of tooling is the major factor in determining quality and cost of graphite/thermoplastic parts. Matched metal tools (die sets) should always be used.

11.5 COST ANALYSIS

1. The manhours required to produce a thermoplastic door are estimated to be less than a comparable metal door; however, the material costs for the graphite make the composite door more expensive.

2. The thermoplastic composites are potentially lower in cost than the epoxy composite based upon the cost of the raw materials. The estimated costs of the thermoplastic prepreg, however, are higher than the epoxy systems. It is recommended that work begin with material suppliers to explore methods of realizing the low cost potential.